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COMPUTER SCIENCE SECTION

# SUMMARY OF AWARDS

Fiscal Year 1981

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NATIONAL SCIENCE FOUNDATION
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Computer Science Section
Washington, DC 20550

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NATIONAL SCIENCE FOUNDATION
Directorate for
Mathematical and Physical Sciences
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Computer Science Section
Washington, DC 20550

# Preface

The purpose of this report is to provide the scientific community with a summary of those grants awarded by the Computer Science Section of the Division of Mathematical and Computer Sciences in fiscal year 1981. The report lists fewer than the actual number of projects currently receiving support because the duration of some grants exceeds one year.

Similar areas of research are grouped together for reader convenience. The reader is cautioned, however, not to assume these categories represent either the totality of interests of each program or the total scope of each grant. Projects may bridge several programs or deal with topics not explicitly mentioned herein. Thus, these categories have been assigned administratively and for the purposes of this report only.*

In this document, grantee institutions and principal investigators are identified first. Award identification numbers, award amounts, and award durations are enumerated after the individual project titles. Within each category, awards are listed alphabetically by state and institution.

Readers wishing further information on any particular project described in this report are advised to contact principal investigators directly.

Kent K. Curtis
Section Head
Computer Science Section

* To get an idea of the scope of possible programs, consult *What Can Be Automated? The Computer Science and Engineering Research Study (COSERS)*, Bruce Arden (Ed.), MIT Press, Cambridge, MA (1980).

# Contents


| | Page |
|---|---|
| Preface | iii |
| Table of Contents | iv |
| Introduction | vi |
| Staff | viii |
| Summary | ix |
| Computation Mathematics | 1 |
| Theoretical Computer Science | 5 |
| Concrete Complexity and Analysis of Algorithms | 5 |
| Parallel, Distributed, and Data Base Models | 12 |
| Abstract Complexity | 15 |
| Foundations of Computer Science | 17 |
| Automata and Language-based Models | 19 |
| Software Systems Science | 21 |
| Programming Languages and Compilers | 21 |
| Operating Systems | 24 |
| Data Base Systems | 25 |
| Formal Structure of Programs | 25 |
| Concurrency | 27 |
| Verification | 28 |
| Computer Systems Design | 31 |
| VLSI Design Methodology | 31 |
| Computer System Architecture | 33 |
| Fault Tolerance and Reliability | 37 |
| Computer System Performance Measurement and Evaluation | 37 |
| Computer Graphics | 39 |
| Software Engineering | 41 |
| Quality Software | 41 |
| Symbolic and Algebraic Manipulation | 43 |
| Software Studies and Metrics | 43 |
| Program Testing and Verification | 45 |
| Software Tools and Programming Environments | 46 |
| Intelligent Systems | 51 |
| Computer Vision and Image Processing | 51 |
| Natural Language and Signal Understanding | 54 |
| Automatic Theorem Proving and Inference | 55 |
| Knowledge Representation and Problem Solving | 57 |
| Special Projects | 61 |
| Data Handling, Data Manipulation, and Database Research | 61 |
| Privacy & Security | 63 |
| The Societal Impact of Computing | 64 |
| Modelling & Simulation | 65 |
| Networking, Computer Communications, & Distributed Computing | 66 |
| Other Projects, Symposia, Colloquia, and Studies | 66 |

Computer Science Research Equipment ..... 69
Coordinated Experimental Research ..... 71
Experimental Computer Research ..... 71
New Faculty Investigators in Experimental Research ..... 72
Computer Science Research Network (CSNET) ..... 73

# Introduction

This report provides summaries of awards made by the National Science Foundation (NSF) through the Computer Science Section in Fiscal Year 1981. In Fiscal Year 1981, Computer Science Section award activities were carried out through seven programs. Topics of interest to the Foundation include, but are not limited, to the following:

## Theoretical Computer Science

Theories of computation and formal languages; analysis of algorithms; theoretical models for computation; and other theoretical problems concerned with the foundations of computer science.

## Software Systems Science

Conceptual basis for the specification of future software systems and the necessary experimentation with such systems, including: advanced programming languages and optimizing compilers; functional and relational specification; program transforming systems; systems for the verification and proof of correctness of programs; the study of the concurrency of operations; the discovery of new algorithms and improved measures of effectiveness of known algorithms.

## Computer Systems Design

Principals of computer systems design relating to the structure of computer systems or the process of systems design. Topics include, but are not limited to: computer system architecture; distributed computer systems; integrated hardware/software systems; performance measurement and evaluation; fault tolerant systems; logic design; computer graphics; man- machine interaction; and VLSI design methodology. The scope of this program includes experimental implementation where that is an integral part of the research.

## Software Engineering

The structure and design process of computer software, especially verification, testing, portability, reliability, and human interfacing to numeric and non-numeric softrware systems. Areas of emphasis include: program validation and testing; software tools; and human factors in software design and use. The program also supports research in computationally oriented numerical analysis, the design and construction of high quality portable software for scientific research, and experimental implementation where that is an integral part of the research.

## Intelligent Systems

Computer-based systems that have some of the characteristics of intelligence. Relevant areas include: pattern recognition; pattern generation; knowledge representation; problem solving; natural language understanding; theorem proving; and areas related to the automatic analysis and handling of complex tasks.

## Special Projects

New directions in computer science and applications including computer networks; database management; computer-based modeling; privacy and security of computer systems; and other topics of special interest in computer science.

## Coordinated Experimental Research

*Experimental Computer Research*—The establishment and enhancement of experimental research facilities, needed technical and professional support personnel, and necessary maintenance of facilities; large multi-investigator projects in experimental computer research (5 year awards expected).

*New Faculty Investigators in Experimental Research*—Establish creative research programs for new faculty with high potential for research in experimental computer science by relieving them partially of the usual obligations of a heavy teaching load and committee work during the initial period of their academic careers (3 year awards expected).

*Computer Science Research Network (CSNET)*—Build a logical computer-based communication network spanning ARPANET, public packet networks, and PHONENET, a telephone-based relay system; provide communication services, file transfer, and access to remote databases; stimulate new classes of network research activities.

## Additional Information

For additional information on any of the projects, contact the Principal Investigators directly.

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| Theoretical Computer Science | John C. Cherniavsky | (202) 357-7349 |

November 1981

# Summary

| | Number of Projects | Value of Awards |
|---|---|---|
| Computational Mathematics | 15 | $643,095 |
| Theoretical Computer Science | 81 | $3,119,111 |
| Concrete Complexity and Analysis of Algorithms | 37 | $1,598,090 |
| Parallel, Distributed, and Data Base Models | 12 | $350,253 |
| Abstract Complexity | 12 | $368,236 |
| Foundations of Computer Science | 14 | $614,838 |
| Automata and Language-based Models | 6 | $187,694 |
| Software Systems Science | 35 | $3,168,548 |
| Programming Languages and Compilers | 15 | $1,360,695 |
| Operating Systems | 1 | $38,799 |
| Data Base Systems | 2 | $154,541 |
| Formal Structure of Programs | 8 | $925,497 |
| Concurrency | 4 | $316,367 |
| Verification | 5 | $372,649 |
| Computer Systems Design | 38 | $2,579,361 |
| VLSI Design Methodology | 7 | $308,531 |
| Computer System Architecture | 16 | $1,180,034 |
| Fault Tolerance and Reliability | 2 | $194,754 |
| Computer System Performance Measurement and Evaluation | 6 | $415,257 |
| Computer Graphics | 7 | $480,785 |
| Software Engineering | 32 | $1,943,234 |
| Quality Software | 7 | $499,147 |
| Symbolic and Algebraic Manipulation | 3 | $151,989 |
| Software Studies and Metrics | 6 | $363,459 |
| Program Testing and Verification | 3 | $174,040 |
| Software Tools and Programming Environments | 13 | $754,599 |
| Intelligent Systems | 42 | $2,558,396 |
| Computer Vision and Image Processing | 13 | $773,751 |
| Natural Language and Signal Understanding | 7 | $536,133 |
| Automatic Theorem Proving and Inference | 9 | $517,010 |
| Knowledge Representation and Problem Solving | 13 | $731,502 |

| | Number of Projects | Value of Awards |
|---|---|---|
| Special Projects | 28 | $1,402,364 |
| Data Handling, Data Manipulation, and Database Research | 10 | $585,580 |
| Privacy & Security | 7 | $218,582 |
| The Societal Impact of Computing | 2 | $255,822 |
| Modelling & Simulation | 2 | $227,580 |
| Networking, Computer Communications, & Distributed Computing | 2 | $56,000 |
| Other Projects, Symposia, Colloquia, and Studies | 5 | $58,800 |
| Computer Science Research Equipment | 10 | $1,015,746 |
| Coordinated Experimental Research | 15 | $5,691,751 |
| Experimental Computer Research | 5 | $3,774,566 |
| New Faculty Investigators in Experimental Research | 5 | $334,972 |
| Computer Science Research Network (CSNET) | 5 | $1,582,213 |

# Computational Mathematics

San Jose State University; Leslie V. Foster; *Generalizations of Laguerre's Method: Lower Order Methods*; (MCS-8101926); $10,197; 6 mos.

Laguerre's method is an efficient and reliable method of finding zeroes of polynomials and certain other functions. Probably the most outstanding feature of Laguerre's method is that it has guaranteed convergence, independent of the initial guess, to zeroes of polynomials with only real zeroes. A variety of generalizations of Laguerre's method that share with Laguerre's method the above global convergence property have recently appeared in the literature. However, as with Laguerre's method all these generalizations require evaluation of the second derivatives of the function whose zeroes are desired.

This research will involve generalizations of Laguerre's method which do not require second derivatives and in this sense are simpler than Laguerre's method. The methods have a lower order of convergence and include variations of Newton's method, the secant method, and Muller's method, as well as other methods. All these methods have attractive global convergence properties and many should be more efficient than Laguerre's method. The methods will be developed and compared with alternate methods via computer implementation for problems of interest such as the eigenvalue problem.

Stanford University; Gene H. Golub; *Numerical Linear Algebra*; (MCS-7811985 A03 & A04); $94,293; 12 mos.

This research involves investigations into a number of areas in numerical linear algebra. These include the generalized algebraic eigenvalue problem, updating techniques for matrix factorization, the inverse eigenvalue problem and solutions of sparse systems of linear equations. During all of these studies there will be an emphasis on the development of high quality numerical algorithms which take advantage of recent developments in computer technology.

Colorado State University; Stephen F. McCormick and Gerald D.Taylor; *A Numerical Investigation of Surface Fitting and Mesh Refinement Techniques*; (MCS-8017056 A01); $47,564; 12 mos.

This project is involved in the development and analysis of various iterative methods for solving problems in nonlinear two-point and partial differential boundary values and integral equations (and associated eigenproblems), surface fitting, and algebraic eigenproblems. Investigation will continue into these areas by extending the analysis and numerical experiments, including comparisons with competitive techniques in each area. Special emphasis will be placed upon mesh refinement and surface fitting techniques for very large data sets. A new project area, namely, theoretical analysis of multigrid methods, will also provide a focus of attention.

University of Colorado at Boulder; Richard H. Byrd; *Trust Region Methods for Minimization*; (MCS-8115475); $36,155; 12 mos.

This project involves the development, analysis, and testing of new algorithms for unconstrained and constrained minimization, with particular emphasis on algorithms using trust regions. There are four main topics: 1) Develop algorithms using rectangular trust regions, in the hope that they will offer advantages over ellipsoidal trust regions, especially in such applications as linearly constrained minimization and successive quadratic programming for nonlinearly constrained minimization. 2) Use prescriptive trust regions in minimization algorithms using majorizing quadratic models. This should enable us to produce significantly faster algorithms for specific classes of problems. 3) Continuation of our research on minimization algorithms using conic models of the objective function, which so far appears to be a very promising area. Many new aspects are suggested, including another new use of trust regions. 4) Continuation of our research in indefinite linearly constrained minimization, especially considering trust region strategies and strategies for dropping active constraints.

In addition, a new algorithm for augmenting a symmetric matrix to be positive definite that has application to many of these topics will be developed.

University of Colorado at Boulder; Karl E. Gustafson; (In colaboration with David P. Young, Boeing Computer Services); *Industry/University Cooperative Research: Computational*

***Studies and Software Development in Hydrodynamics, Concentration Diffusion Equations, and Chemical Kinetics***; (MCS-8012220); $20,348; 12 mos. (Joint support with the Industry/University Cooperative Program-Total Grant $61,661).

Computational studies and software development will be performed for problems in three-dimensional hydrodynamics, concentration-diffusion equations, and chemical kinetics. This work will be carried out on a cooperative university-industry joint-work basis at the University of Colorado and the Boeing Laboratories. These studies play a role in the understanding of the onset of instabilities in hydrodynamics leading to turbulence, flow of substances and mixed concentrations through porous media, and in bifurcation theory for thermal ignition, combustion problems, and rapid chemical mixing.

Yale University; Martin H. Schultz and Stanley C. Eisenstat; ***Efficient Solution of Large Sparse Systems of Linear Equations***; (MCS-8104874); $24,998; 12 mos.

In solving large sparse systems of linear equations using a direct method such as Gaussian elimination, the storage required can easily exceed the amount of memory available, even though the problem (i.e., the nonzero elements of the coefficient matrix and the right-hand side) can be represented in memory. One solution is the use of auxiliary storage, but the straight-forward approach to integrating auxiliary storage into a sparse matrix code is characterized by excessive input/output to random access storage.

A different problem arises in implementing sparse elimination on vector processors where the straightforward approach requires dealing with sparse vectors and doing scatter-fetch/scatter-store operations, operations incompatible with the vector hardware and thus unable to take full advantage of the speed of such machines.

A solution to both of these problems may be found in the implementation of a Minimal Storage Sparse Elimination algorithm which we proposed several years ago. We will investigate this approach to auxiliary storage sparse elimination and sparse elimination on vector processors.

University of Kentucky; Graeme Fairweather; ***Boundary Methods for Elliptic Boundary Value Problems***; (MCS-8102295); $13,912; 24 mos. (Joint support with the Applied Mathematics Program-Total Grant $26,912).

This project is concerned with the numerical solution of boundary value problems for elliptic partial differential equations. Both theoretical and computational studies will be conducted on some techniques for finding an approximate solution for linear elliptic boundary value problems which arise in potential theory and elasticity. A thorough study of quadrature methods for use in three dimensional problems will also be conducted.

University of Maryland; Frank W. J. Olver; ***Asymptotic and Numerical Approximations***; (MCS-8111725); $5,000; 36 mos. (Joint support with the Applied Mathematics Program-Total Grant $50,000).

First Objective. To apply relative-precision error analysis to the evaluation of polynomials and solution of tridiagonal systems of linear algebraic equations, and to extend the general theory to complex variables.

Second Objective. To construct unrestricted computing algorithms for the sine, cosine, logarithm, and inverse trigonometric functions.

Third Objective. To apply relative-precision error analysis to the solution of ordinary differential equations, especially Bessel's equation, both for real and complex variables.

Fourth Objective. To construct new asymtotic theories for second-order differential equations with a coalescing simple turning point and simple pole, or a coalescing simple turning pole and double pole.

University of Minnesota; J. B. Rosen; ***Global Optimization Methods for Linearly Constrained Large-Scale Problems***; (MCS-8101214); $44,954; 12 mos.

The goal of this research is to develop efficient computational algorithms which find the global minimum of a concave function subject to linear constraints. The emphasis will be on methods suitable for large-scale problems where most of the variables appear only linearly in the objective function. In these methods, linear and nonlinear variables will be treated differently, so that the global solution of large, sparse problems can be obtained in a reasonable amount of time, provided only that the number of nonlinear variables is relatively small. It is also intended to produce an efficient and reliable software implementation of one or more of the best algorithms, and to thoroughly test such implementations on a variety of realistic problems.

This research represents a cooperative research effort between Professor J. B. Rosen of the University of Minnesota and Dr. E. H. McCall of Sperry-Univac.

New York University; Michael L. Overton; *Numerical Methods for Non-Smooth Optimization Problems*; (MCS-8101924); $40,000; 24 mos.

This project involves the investigation of numerical methods for solving certain non-smooth optimization problems. The main problem currently of interest is that of minimizing a sum of Euclidean norms of linear vector functions. This problem has a large variety of applications both in physics (e.g. minimal surface problems) and in economics (e.g. location problems). The function to be minimized is not differentiable everywhere and this fact makes the problem quite difficult to solve. The principal investigator is currently developing a new method for solving this problem, based on Newton's method for unconstrained optimization and projection techniques associated with constrained optimization. The method is related to an algorithm for nonlinear optimization developed by the principle investigator. Preliminary theoretical analysis and numerical experiments indicate that the new method is very efficient. The purpose of this project is to continue this work, with three goals: an improved mathematical framework, efficient and reliable numerical algorithms, and convenient general-purpose software.

New York University; Olof Widlund; *Fast Methods for the Solution of Large Finite Difference and Finite Element Systems of Equations*; (MCS-7902882 A02); $41,800; 12 mos.

This research involves work on efficient methods for solving highly structured finite difference and finite element systems of equations. The goals of the research are threefold, to provide an improved mathematical framework, fast and reliable numerical methods and a convenient FORTRAN Program for the solution of finite element approximation to large systems of difference and differential equations.

University of Pittsburgh; Werner C. Rheinboldt; *Computational Continuation Processes for the Solution of Nonlinear Systems of Equations*; (MCS-7805299 A03); $48,202; 12 mos.

This research program concerns the development and analysis of adaptive computational continuation algorithms considered, in a broad sense, as the collection of all methods necessary for a computational analysis of specified parts of the solution field of equations of the form $F = b$ where $f: R^m \to R^n$ is a given mapping and $m>n$. Some of the topics to be addressed are the detailed analysis of classes of predictor-continuation methods and the design of efficient step controls for them; investigation of the use of incremental formulations to compute or approximate the derivative of F; studies of numerical methods for bifurcation problems; design and analysis of adaptive parameter change algorithms, and their incorporation into the continuation processes; investigation of the influence of input changes upon the location of the limit points; general stability studies of the problems and methods considered; and last but not least the development of complete prototype programs for the analysis of solution fields and their use in an experimental assessment of the merits of the various methods and approaches.

University of Texas at Austin; David Young and David Kincaid; *Research and Development of Iterative Algorithms and Software for Elliptic Partial Differential Equations*; (MCS-7919829 A01); $48,912; 12 mos. (Joint support with the Applied Mathematics Program-Total Grant $65,236).

This project involves research and development of iterative algorithms and software for solving large systems of linear algebraic equations with sparse matrices. Particular emphasis will be placed on linear systems arising from the numerical solution of elliptic partial differential equations.

The work will have two aspects, namely, development of research-oriented software and research on iterative algorithms. The first aspect of the work will involve a substantial expansion of the capability of the ITPACK package to include more powerful iterative algorithms and to allow for handling more general classes of linear systems including systems with nonsymmetric matrices. It will also involve continued participation in the ELLPACK project. The second aspect of the work is closely related to the first and involves research on iterative algorithms with emphasis on effective methods for solving nonsymmetric linear systems.

University of Virginia; Lois Mansfield; *Finite Elements in Partial Differential Equations*; (MCS-8016532 A01); $67,815; 24 mos.

This project will study finite element methods for the numerical solution of partial differential equations arising primarily from nonlinear problems in solid mechanics. In particular, the large deformation analysis and the buckling of shells and plates are an important aspect of the analysis of structures. The finite element method is being used to provide numerical solutions to these problems. The research in this area is still in the beginning stages

and there are many open problems, both in the formulation and mathematical analysis of the methods and in the solution of the resulting nonlinear algebraic equations.

University of Wisconsin-Madison; Olvi L. Mangasarian, R. R. Meyer, and S. M. Robinson; ***Computation and Theory in Nonlinear Programming***; (MCS-7901066 A02); $98,943; 12 mos.

The investigators will conduct research in several areas of mathematical programming. The areas to be investigated include piecewise-linear problems, large scale optimization, and general nonlinear programs. They will research both general theory and algorithmic techniques in these areas. Computational testing of the algorithms developed will be carried out on realistic problems in such areas as free boundary problems and pipeline network analysis.

# Theoretical Computer Science

## Concrete Complexity and Analysis of Algorithms

University of California-Berkeley; Richard M. Karp; *Combinatorial Algorithms and Computational Complexity*; (MCS-8105217); $61,919; 12 mos.

This research focuses on six interrelated themes: probabilistic analysis of algorithms, randomized algorithms, algorithms for determining the reliability of a complex system, algorithms for the enumeration of graph-theoretic objects, machine-based complexity theory and concrete complexity theory. Tools from computational complexity, operations research, and combinatorics are used to discover upper and lower time and space bounds for problems in these areas.

University of California-Berkeley; Eugene L. Lawler; *Combinatorial Algorithms*; (MCS-7820054 A01); $112,000; 24 mos.

The research is concerned with algorithms for solving "polymatroidal" network flow problems, the polymatroidal matching problem, and problems in sequencing and scheduling. Although emphasis is given to the development of polynomial time algorithms, attention is also given to NP-completeness results.

University of California-Irvine; George S. Lueker; *The Analysis of Searching Problems*; (MCS-7904997 A01); $59,364; 24 mos.

The research has two components. The first deals with the probabilistic analysis of problems in computer science especially problems involving searching for optima. Specific problems investigated include finding optimum subgraphs in weighted graphs, knapsack problems, search tree analysis, and sorting. In addition, application of probabilistic methods to problems such as efficient design of parallel processing systems are studied. Finally, we consider the development of reductions which use probabilistic methods to show that certain problems are hard.

A second component of the proposed research deals with the development of efficient algorithms which search for records, or for sets of records, satisfying some constraint. We investigate a variety of questions related to balanced trees.

University of California-San Diego; Te Chiang Hu; *Theory and Computation of Discrete Optimization*; (MCS-8003362 A01 & A02); $55,194; 24 mos.

The class of network flow problems is a subclass of linear programming problems, but special algorithms are needed for the network flow problems. Now, there is a subclass C of dynamic programming problems which also needs special algorithms. The dynamic programming needs $0(n^3)$ time to solve the class C while the investigator has developed algorithms requiring $0(n \log n)$ or $0(n^2)$ time to solve many problems in the class C including alphabetic codes, N-order statistics, matrix computation, etc. The investigator will characterize the class C and develop new algorithms and data structures to solve the problems in C.

University of Southern California; Leonard Adleman; *Computational Complexity and Its Relationship to Number Theory*; (MCS-8022533 & A01); $83,421; 24 mos.

Research is planned in three areas: Computational complexity, cryptography, and VLSI.

1. Computational Complexity. Several aspects of computational complexity will be investigated with particular emphasis on its relationship to number theory. Much will center on the P=NP problem.
2. Cryptography. Public security and privacy.
3. VLSI. The VLSI related prooblems are; layout, design aids, design paradigms, and complexity.

Yale University; Daniel Gusfield; *Algorithms for Dynamic Combinatorial Computing*; (MCS-8105894); $44,354; 24 mos.

Dynamic combinatorial computing is concerned with combinatorial computing problems in which some part(s) of the problem description change frequently and where the problem must be re-solved in response to each change. The dynamic approach is

motivated by the very common occurrence of long sequences of problem instances where each instance differs from the others by small or structured modifications of the problem data. The general goals of research in dynamic combinatorial computing are to find preprocessing methods allowing the fast solution of each instance of a related set of problem instances; to find data structures and methods for fast updates of problem solution in response to data modifications; to find algorithms and theorems that identify which data modifications actually affect the problem solution; to find time-space trade-offs for partial precomputation and storage methods; and to find complexity results to understand the costs and limitations of the above approaches.

The research is directed towards converting classical static combinatorial algorithms to dynamic algorithms; towards dynamic graph theory problems arising in distributed computing environments; towards time-space trade-off for on-line problems constrained by space; and towards multi-criterion scheduling problems.

University of Georgia; Carl Pomerance; ***Number Theory: Primality and Factorization***; (MCS-8002694 A01); $11,380; 24 mos. (Joint support with the Algebra and Number Theory Program-Total Grant $22,763).

An integer larger than 1 is said to be prime if it has no factors other than itself and 1. A celebrated problem is to find a quick procedure for deciding if a given number n is prime or not. A recent development is a very quick algorithm due to Professor Pomerance and his collaborators L. Adleman and R. Rumely. However, there is still room for improvement since this algorithm does not quite run in polynomial time (i.e. the number of steps is not less than a common power of numbers of digits of n). Professor Pomerance will study this problem of finding a fast prime testing algorithm. In addition Professor Pomerance will study the normal number of prime factors of the Euler phi function. The function denotes the number of integers among 1,2,...,n that are relatively prime to n.

Northern Illinois University; Marvin Winderlich; ***Factoring Large Composite Numbers on Parallel Machines***; (MCS-8103725); $19,946; 24 mos. (Joint support with the Algebra and Number Theory Program-Total Grant $26,946).

This research involves the investigation of the problem of factoring large composite integers. The research for this grant includes an analysis of several frequently mentioned methods for improving the continued fraction method of factoring, an actual implementation of the method on the English DAP parallel computers, and a small scale test implementation of R. Schroeppel's new sieve-method of factoring. The research is being performed at Northern Illinois University and Queen Mary University of the University of London.

Northwestern University; Robert E. Bixby; ***Combinatorial Investigations in Mathematical Programming***; (MCS-8104881); $73,788; 24 mos.

The program of research is based on the application of combinatorial techniques to the study of mathematical programming and related problems. The emphasis of the research is on the development of efficient algorithmic procedures.

The combinatorial techniques used are drawn primarily from matroid theory, graph theory and polyhedral combinatorics.

The specific areas of research are the following:

1. Development of explicit computational methods, including computer codes, for uncovering structure in linear programming problems when such structure is hidden or masked in some nontrivial way;
2. Investigation of the algorithmic and matroid-theoretical implications of recent work on totally unimodular matrices—this work has already had significant impact on general matroid theory, as well as certain questions in the theory of computational complexity; and
3. Development of a direct algorithmic solution for the problem of testing membership in a general polymatroid, or what is the same, testing membership in the core of a convex n-person cooperative game (sidepayments).

Indiana University-Bloomington; Paul W. Purdom and Cynthia Brown; ***Average Time Analysis of Algorithms for NP-Complete Problems***; (MCS-7906110 A01); $65,164; 24 mos.

The average time required to solve random NP-complete sets is studied. The approach used consists of analyzing backtracking algorithms on representative problem sets. The problem sets are chosen to reflect several reasonable statistical distributions and on average time analysis is performed.

NP-complete problems are usually solved by backtracking. Backtracking usually requires much less than a worst case analysis would suggest. The quality of various backtracking algorithms is made clear by comparing the average amount of time that

they require on representative problem sets. The average time required by various backtracking algorithms and the development of improved algorithms are studied.

Louisiana State University; Charles N. Delzell; ***Hilbert's 16th and 17th Problems***; (MCS-8102744); $5,826; 24 mos. (Joint support with the Algebra and Number Theory Program-Total Grant $17,480).

Professor Delzell will attempt to solve three problems in real algebraic geometry:

1. To establish unfeasibly large lower bounds on the computational complexity of any algorithm which solves the first part of Hilbert's 16th problem, namely that of determining the possible configurations of the ovals of a nonsingular real projective plane algebraic curve of a given fixed degree d (an unfeasible algorithm, based upon the Tarski-Seidenberg algorithm, is easy to describe);
2. To extend his continuous solution of Hilbert's 17th problem (that of representing positive semi-definite forms in several real variables as sums of squares of homogenous rational functions) from the case where the field of coefficients is real closed to the case where it is merely ordered; and
3. To improve his "Finiteness Theorem for open semi-algebraic sets."

Johns Hopkins University; S. Rao Kosaraju; ***Applications of Basic Theory of Computing***; (MCS-7905163 A02); $41,405; 12 mos.

This research is concerned with the application of automata and other basic areas to more practical problems in computing. The problems selected are from the design of sequential and parallel algorithms, simulation of data structures and information retrieval.

1. The inter-relationship between common data structures like stacks and double ended queues (deques) will be investigated,
2. The development of data structures and algorithms for searching a dictionary will be studied and
3. The application of known techniques of parallel processing to image processing as well as new design techniques applicable to parallel processing of arrays will be investigated.

Massachusetts Institute of Technology; Ravindran Kannon; ***Computational Complexity of Numerical Algorithms***; (MCS-8105557); $33,208; 24 mos.

Three areas are investigated-computational complexity of numerical algorithms, relations between uniform and nonuniform complexity measures, and the complexity of algebraic problems. The first endeavour is a continuation of the efforts by the principal investigator to design efficient algorithms for problems in which the growth of the number of bits of intermediate numbers produced during the solution of the problem plays a significant role in determining the complexity of the algorithm. Computational work with the polynomial-time Smith and Hermite normal form algorithms already designed by the principal investigator, further generalization to matrices with polynomial entries, G.C.D. of polynomials and the knapsack problem are pursued. Under the second topic, bounds are derived on nonuniform complexity measures-mainly circuit size and formula length-for languages in given uniform complexity classes. Under the third topic, relevant pieces of algebraic number theory are made constructive and the decidability of the orbit problem is generalized.

Massachusetts Institute of Technology; Ronald Rivest; ***Concrete Computational Complexity***; (MCS-8006938); $85,323; 12 mos.

This research is concerned with the study of algorithms and computational complexity in the area of VLSI design and the theory of cryptology. The approach to VLSI design involves developing component packing algorithms and wire routing algorithms subject to the constraints imposed by VLSI manufacturing techniques. The approach to cryptology research involves the development of a conceptual framework that allows the measurement of the security of cryptosystems. This conceptual framework rests upon the development of a theory of "finite" computational complexity.

Massachusetts Institute of Technology; Michael Sipser; ***Computational Complexity and Algorithms***; (MCS-8105555); $34,834; 24 mos.

The emphasis of this research is on the study of problems which have apparent exponential complexity, yet for which no superpolynomial lower bound is known.

Two problems, in particular, are investigated. The first is the conversion of nondeterministic two-

way finite automata to deterministic two-way finite automata. The second is the complexity of boolean functions-in particular the investigation of the parity function in terms of circuit complexity when the depth of the circuit is bounded. For the latter problem topological tools are used.

Worcester Polytechnic Institute; Paul W. Davis; ***Regional Conference on Graph Algorithms—Worcester, Massachusetts—June 15-19, 1981***; (MCS-8106172); $9,072; 6 mos. (Joint support with the Special Projects Program-Total Grant $18,144).

This conference is one of a series of five (5) day regional conferences being funded by the NSF. Supporting services for the handling of the proposals for these conferences and for the conduct of these conferences is provided by the Conference Board of the Mathematical Sciences (CBMS) through the medium of a contract with the Foundation. The objective of these conferences is to stimulate and broaden research activity across the spectrum of the mathematical and computer sciences, particularly in areas where such activity is lagging. Each conference has a principal lecturer (generally not from the host institution) and about twenty-five (25) other invited participants, drawn from the broad geographic region around the host institution. There will be at least two lectures by the principal lecturer each day, with the remainder of the day available for study, informal seminars, and exchange of ideas. These lectures will be published as research monograph by either the American Mathematical Society or the Society for Industrial and Applied Mathematics.

The lectures of this conference will be given by Professor Tarjan of the Computer Science Department of Stanford University.

On each of the five mornings of the conference (June 15-19, 1981), Professor Tarjan will deliver two hour and one-half lectures describing algorithms for such network optimization problems as minimal spanning tree, maximum flow/matching, shortest path, etc. Emphasis will be on the description of those algorithms which are currently the fastest known.

University of Minnesota; Oscar Ibarra; ***Complexity of Computations***; (MCS-8102853); $78,020; 24 mos.

The research involves the following topics:

1. Deterministic and nondeterministic resource bounded computations and their tradeoffs.
2. The power of low level nondeterministic computing devices.
3. Decidable cases of Hilbert's tenth problem.
4. Investigation of probabilistic algorithms for difficult deterministic tasks.
5. Heuristics for obtaining approximate solutions to NP-complete problems. The techniques used in investigating the above problems consist of tools from classical automata theory, formal language theory, and mathematical logic applied to problems translated from their original domain to one in which the tools are applicable.

University of Minnesota; Sartaj K. Sahni; ***Algorithmic Study of Combinatorial Problems***; (MCS-8005856 A02); $53,191; 12 mos.

The research is concerned essentially with the study of combinatorial problems, particularly those arising in graph theory, scheduling theory, design automation, and some branches of operations research. Most of the problems that will be studied are known to be NP-hard. Hence, it is very unlikely that any of them can be solved by an efficient (i.e. polynomial time) algorithm. The investigation of these problems will focus on the following issues:

1. Identify large interesting subclasses of the NP-hard problems that can be solved in polynomial time.
2. Obtain good heuristics to solve the problem. i.e., obtain algorithms with a good average behavior.
3. Obtain a characterization of the smallest (or simplest) subclass of the problem that is NP-hard.
4. Obtain good (and fast) approximation algorithms.
5. Obtain subexponential algorithms for the general problem.

University of New Hampshire-Durham; Dov Harel; ***Dynamic Data Structures and Their Algorithms***; (MCS-8105325); $25,196; 24 mos.

The major area of research is the development of efficient data structures and algorithms for various versions of the lowest common ancestors problem. Some applications of algorithms to solve the problem in various dynamic settings are already known. There is some evidence that such algorithms may be useful for a wider variety of graph algorithms. Recent work concerning the off-line versions of the problem indicates that the problem is also of considerable theoretical interest.

The second major area of research is concerned with fast updates of balanced tree schemes. The research on data structures which support fingers, which attracted attention during the last decade, indicates that searching a balanced tree, and updating it, are to a great extent independent of each other. This raises a question which is of interest in its own right, namely how fast can we update a balanced tree, once the location of the update is known? The answer to this, as well as related problems, may shed some light on the difference between various balanced tree schemes.

Princeton University; David P. Dobkin; ***Unifying the Study of Geometric Algorithms***; (MCS-8114207); $107,739; 24 mos.

The complexity of geometric algorithms has been studied for only five years. In that short time, the area has evolved into a central theme within the analysis of algorithms area. This research is concerned with finding new procedures to unify and extend our previous knowledge of the processes necessary to automate geometry. The specific areas of study are:

1. Testing for polyhedral intersections.
2. Data structures for geometric organizations.
3. Geometric optimization problems.

Princeton University; Richard J. Lipton; ***Computational Complexity***; (MCS-8023806 A01); $38,046; 12 mos.

This research is aimed at the following questions:

1. How do we construct fast algorithms for a wide class of problems?
2. Why are some problems inherently difficult?

In addition, it is intended to study specific problems of interest to computer science and engineering, namely; model theory, graph isomorphism, etc.

Other problems to be attacked are questions of complexity of certain Turing machine models and RAM models and simulations of nondeterministic Turing machines by deterministic ones.

Cornell University; Bengt Aspvall; ***Efficient Algorithms***; (MCS-8105556); $33,326; 24 mos.

The problems to be studied are in the area of design and analysis of algorithms. Efficient algorithms for sparse matrix problems, linear programming problems, and satisfiability testing are all studied. The problems are modeled as problems on graphs and solved using graph-searching algorithms. The specific goal is to obtain collections of efficient sparse matrix algorithms and combinatorial optimization algorithms applicable to verification systems.

Cornell University; Juris Hartmanis; ***Computational Complexity***; (MCS-7800418 A06 & A07); $93,168; 12 mos.

This research includes a study of the computational complexity of feasible computations and a related investigation of formally provable computational complexity properties. In particular, the intention is to concentrate on the study of the structure of natural families of computations and the properties and relations between complete problems of these families. As a parallel to this study, will be an investigation of the formally provable properties about complexity of computations and their applications to computational complexity theory.

A portion of this grant is for the purpose of supporting the collaborative research of Professor Charles Kelemen of LeMoyne College.

Cornell University; John Hopcroft; ***Theory of Algorithms***; (MCS-8101220); $75,045; 12 mos.

The research involves investigating practical methods (using probabilistic algorithms) for solving problems for which no polynomial time algorithms are known and investigating applications of theoretical computer science to problems in VLSI design and organization.

Institute of Electrical & Electronic Engineers; Allen Gersho; ***IEEE Communications Security Workshop: August 24-26, 1981; Santa Barbara, California***; (ECS-8117145); $3,200; 6 mos. (Joint support with the Electrical & Optical Communication Program and Special Projects Program-Total Grant $10,000).

IEEE Communications Security Workshop is being held on August 24-26, 1981 at the University of California, Santa Barbara, California. The objective is to delineate the state-of-the-art and future directions of research relating to the protection of the integrity, confidentiality and authenticity of electronically-communicated information , including cryptography, voice scrambling, and network security. Technical areas that are receiving attention are cryptographic theory, key management, system implementation techniques, and standards and protocols.

State University of New York-Stony Brook; Alan C. Tucker; ***Perfect Graphs, Circular-arc Graphs, and Associated Algorithms***; (MCS-8102701); $7,000; 24 mos. (Joint support with the Algebra and Number Theory Program-Total Grant $27,485).

The objectives of this program are:

1. Continuation of research on validation of Berge's Strong Perfect Graph Conjecture and related coloring problems. Let a(H) be the size of the largest set of mutually adjacent vertices in graph H and t(H) be the size of the largest set of mutually adjacent vertices such that all vertices of H are in one of the subsets. A graph is perfect if for all (vertex-induced) subgraphs H, a(H)=t(H). Berge conjectured that a graph G is perfect if and only if G and its complement contain no triangle-free odd-length circuits. Verifying the conjecture for special classes of graphs and developing related coloring theory and coloring algorithms are the objectives.
2. Continuation of research on characterizations and algorithms for circular-arc graphs and their coloring. A graph G is a circular-arc graph if there exists a family F of arcs on a circle and a 1-1 correspondence between vertices of G and arcs of F such that two distinct vertices are adjacent if and only if the corresponding arcs overlap.

Duke University; Arnold Rosenberg; ***Graph Embeddings and VLSI Complexity***; (MCS-8116522); $40,846; 12 mos.

The research deals with two subjects that have received considerable attention in the theoretical computer science community over the last several years: graph embeddings and combinatoriai aspects of integrated circuitry, especially VLSI.

One problem area to be investigated involves similarity of graph families: one fixes on a specific family of graphs, and one seeks general conditions that guarantee that a given second family of graphs has the same "proximity structure" as the fixed family. Cost tradeoffs in graph embeddings, with applications, will also be investigated.

Finally, the applications of graph embeddings studies for the circuit layout problem will be pursued. In particular, what distortions of grids other than squaring them up (a) may facilitate circuit realization, and (b) can be effected with bounded lengthening of wires and bounded expansion of chip area?

Ohio State University; Paul Seymour; ***Structure Theorems for Graphs and Matroids and Discrete Optimization***; (MCS-8103440); $8,000; 24 mos. (Joint support with the Algebra and Number Theory Program-Total Grant $23,516).

Dr. Seymour works in combinatorial theory and plans to continue his research on the application of structure theorems to discrete optimization. He will concentrate on the structure imposed on graphs and matroids by the combination of connectivity and excluded minor requirements.

Bucknell University; Eugene M. Luks; ***Graph Isomorphism and Related Topics***; (MCS-8102856); $25,407; 24 mos.

The research focuses on the graph isomorphism problem, that is, the problem of recognizing whether there is a one-one correspondence between the vertices of any two given graphs which preserves adjacency. The problem has both theoretical and practical significance. There is no known algorithn which is efficient (succeeds within time bounded by a polynomial function of the number of vertices) for all pairs of graphs. Introducing new algebraic techniques, the principal investigator, Professor Eugene M. Luks, has described the first polynomial-time solutions to important special cases of the problem. There is evidence that the techniques are applicable to other classes of graphs and to the general problem. These extensions are being studied. Also the algorithms are being improved and their relation to the certificate problem-assigning a certificate or code to each graph are being investigated. The algebraic nature of the recent breakthroughs also motivates a general study of the complexity of computational problems in permutation groups. Professor Luks will continue to develop the machinery for such a study.

Pennsylvania State University; Janos Simon; ***Computational Complexity Theory***; (MCS-8104876); $32,363; 24 mos.

Several areas of computational complexity are investigated. These include: parallel algorithms, probabilistic computations, and the use of nonconstructive methods-especially descriptive complexity. The aim of the research is to develop problem solving techniques useful for a wider variety of problems. Particular attention is paid to nondeterminism, parallelism, and lower bound techniques for general computational models.

Society for Industrial and Applied Mathematics; Edward Block; ***Conference on Applications of Discrete Mathematics,***

*Troy, New York, June 10-12, 1981*; (MCS-8100674); $5,000; 6 mos. (Joint support with the Special Projects Program-Total Grant $11,835).

The Society for Industrial and Applied Mathematics will conduct a conference on the applications of discrete mathematics, including combinatorics, discrete optimization, graph theory, and mathematical programming.

The conference is scheduled to take place at Rennselaer Polytechnic Institute on June 10-12, 1981, immediately following the three-day annual meeting of the Society. Objectives of the conference are to:

1. Critically examine recent applications of discrete mathematics.
2. Review recent developments in discrete mathematics that have potential application.
3. Identify problems that have to be solved to enhance the application of discrete techniques.

In conducting this conference, it is the goal of SIAM to bring together researchers in the various fields of discrete mathematics with users of discrete mathematics in industry and government.

University of Pittsburgh; Errol L. Lloyd; *Complexity and Optimization*; (MCS-8103713); $32,259; 24 mos.

The study of several complexity and optimization problems is proposed. These problems have computer related applications in the design of schedulers, memory management systems and VLSI, as well as in industrial scheduling and bin packing applications. There are four main problem areas which we consider: the scheduling of task systems with resources, the worst case of performance of buddy systems, the determination of optimal paging strategies, and the automated layout of integrated circuits. For each particular problem we will study several topics, among them: determining the complexity of the problem, analyzing the worst case performance of existing algorithms for the problem, and finding new heuristics for solving the problem. We expect that the results obtained will have an impact both on practical applications and, more generally, on our understanding of the theory of algorithms.

Brown University; John E. Savage; *Applied Computational Complexity*; (ECS-8024637); $53,010; 24 mos. (Joint support with the Computer Engineering Program-Total Grant $106,021).

This continues the research supported by NSF in the area of applied computational complexity. This is an emerging area in which limits on the performance of algorithms and machines are sought for concrete problems and machine models. Results that are produced here are often stated in the form of tradeoff inequalities which capture limits that must hold simultaneously on several computational parameters. The scope of work is primarily focused in two areas, the performance of VLSI algorithms and space-time tradeoffs. Both topics concern the computation of functions when two or more parameters of computation have to be considered simultaneously. In the case of VLSI the parameters include chip area, the number of cycles executed by the chip and the length of cycles. In the case of space-time tradeoffs the parameters are temporary storage space and computation time. The research examines tradeoffs, that is, limits on the simultaneous realization of the relevant parameters of computation, as well as the design of algorithms to achieve or nearly achieve the limits. The emphasis, however, is placed on the limitations on performance. There is also the possibility of similar tradeoff studies for multidimensional databases, but this is not an area that is expected to receive the principal attention under this grant.

Brown University; Robert Sedgewick; *The Analysis and Implementation of Algorithms*; (MCS-8017579); $60,529; 24 mos. (Joint support with the Software Systems Science Program-Total Grant $121,059).

The research involves the precise mathematical analysis of the running times of a set of fundamental algorithms and their implementations on a variety of computer architectures. Exact closed form solutions for both actual running times and for expected running times are sought. Additionally, for algorithms that are particulary difficult to analyze, statistics on actual running times over large domains of inputs will be collected and curve fitting attempted. As a useful spinoff, the implementations best suited for particular environments will be identified.

Southern Methodist University; David W. Matula; *Foundation of Finite Precision Arithmetic*; (MCS-8012704 A01); $18,115; 12 mos. (Joint support with the Computer Systems Design Program-Total Grant $36,230).

Advances in LSI and VLSI capabilities are fostering an era where complex special purpose hardware for specific application areas will be realizable at acceptable costs. The ability to represent all sufficiently simple fractions and to evaluate rea-

sonably small rational expressions exactly are important features making fixed-slash and floating-slash arithmetic interesting possibilities for special purpose architectures. Previous research has demonstrated that fixed and floating-slash systems are sufficiently competitive in arithmetic logic design requirements and representation and timing efficiencies to be serious candidates for special purpose architectures. The research is directed toward developing and assessing the viability of these arithmetic systems in the most promising areas of application: specifically, (i) assessment of the growth of accumulated error in fixed-slash and floating-slash computations; (ii) investigation of the suitability of these systems for incorporation in symbolic computation packages; (iii) for micro and small minicomputer systems; an assessment of the ability of a single firmware level fixed-slash (or floating-slash) arithmetic package to support moderate user level exact integer, exact rational, and approximate real computation capability; and (iv) investigation of enhancements of particularly extended range for floating-slash and algorithms for special purpose functions such as square root.

University of Houston; Ker-I Ko; *Feasible Computation of Real Functions*; (MCS-8103479); $25,367; 24 mos.

Recent research on feasible computation has been providing insight into the intrinsic difficulty of many combinatorial problems. New notions and techniques such as nondeterministic computation have been developed and successfully applied to these problems. In this project the feasible computations of numerical problems such as the root problem, the integration problem, and the power series problem are investigated. Previous studies have shown that the application of new notions provides new directions for understanding of these basic problems. Based on these findings, a continuous version of the "P=NP" problem is studied to determine its role in the feasible computation of numerical problems. Tools are developed for classifying numerical problems according to their complexity and for relating numerical problems to combinatorial problems. The ultimate goal is the development of a new theory of abstract numerical analysis.

University of Washington; Martin Tompa; *VLSI Design Aids, and Inherent Complexity of Common Problems*; (MCS-8110089); $26,300; 24 mos. (Joint support with the Computer Systems Design Program-Total Grant $52,600).

The potential density of very large scale integrated (VLSI) circuits is increasing at a rate which is rapidly outpacing the ability of designers to exploit that density without the aid of sophisticated automated design systems. This project addresses two aspects of such systems; namely, the automated layout of circuit components and graphic tools for editing VLSI designs. In addition, the inherent complexity of several problems relating to VLSI circuits will be explored.

## Parallel, Distributed, and Database Models

California Institute of Technology; Charles L. Seitz; *Second Caltech Conference on VLSI, January 1981*; (ECS-8025817); $2,800; 6 mos. (Joint support with the Computer Engineering Program and Computer Systems Design Program-Total Grant $11,810).

This conference, similar in plan and emphasis to the 1979 Cal Tech Conference, features the research efforts underway both in industry and universities in VLSI architecture, design, and fabrication. The first day's session, involving invited speakers, is concerned with the possible restructuring of the microcircuit industry based upon the concept of the "silicon foundry" and implementation system. The concept of the "silicon foundry" was discussed in the 1979 conference proceedings. The second and third days are devoted to sessions on fabrication, innovative VLSI designs, computer-aided design, design principles, and computer architectures. Conference proceedings are to be published. The conference attendance is limited to approximately 600, and includes university, industry, and government attendees.

Stanford University; Jeffrey D. Ullman; *Database Theory*; (MCS-8012907 A01); $52,023; 12 mos.

This research pertains to theoretical issues in the design of database management systems. A major part of the research concerns the relational data model and properties of certain integrity constraints, called data dependencies, when applied to relations. It is intended to look at concurrent processing of

transactions and the enforcement of the serialability condition on concurrently executing transactions and to continue investigations into file organization for partial-match retrieval in query languages.

University of California-San Diego; Patrick Dymond; ***Complexity Theory of Synchronous Parallel Computation***; (MCS-8111098); $28,984; 24 mos.

This research is intended to further the development of the complexity theory of parallel computers, a theory which is becoming increasingly important as technological advances permit the construction of machines in which a large number of processing units may be active at any one time. The principal areas of investigation are 1) the effects of bounding the amount of time and the number of processing elements simultaneously; and 2) the effects of changes in the definition of the model of parallel machine. The first of these areas deals with the question of how the two main resources of interest in parallel computers, amount of time and number of processors, will interact; and in particular the relationship between computations in which one of the two resources is severely limited, while the other is held to within a feasible size. The second area studies relationships between various parallel models to develop understanding of the differences among them. The investigation will be carried out using techniques such as simulation, reducibility, relativization and restricted models of computation, which have been applied in other complexity theory contexts.

University of California-San Francisco; Hugo M. Martinez; ***Computer Aided Studies of Evolutionary Systems***; (MCS-8018242); $18,098; 24 mos.

The concept of an adaptive production system is to be generalized in order to achieve evolutionary capability. The generalizing technique consists of providing for a "genetic" memory that will serve as data for generating the procedural memory.

Two specific kinds of adaptive systems are considered: those of Waterman exemplifying a formal language and a procedural memory of changing size, and those of Holland and Reitman exemplifying an informal language and a procedural memory of fixed size.

The form adopted for the corresponding genetic memories assumes that each of these systems already possesses the adapative feature. Serving as a data base for a built in trainer, the genetic memory is used by the latter to train an embryonic adaptive system to cope with rudimentary problems at a level where subsequent, unaided adaptation is reasonably assured.

The specific aim of the study is to obtain embodiments of the genetic memories and trainers for these two kinds of adaptive production systems and to conduct case studies which will assess the resulting evolutionary capability and the ease of design for specific tasks.

University of Illinois-Urbana; Chung L. Liu; ***Combinatorial Algorithms***; (MCS-8107647); $37,330; 12 mos.

The average case and worst case time complexities of a variety of combinatorial algorithms are investigated with particular attention paid to heuristics. The specific algorithms studied include scheduling algorithms, sensitivity analysis of heuristic algorithms, error analysis in dynamic programming problems, graph algorithms, combinatorial properties of trees and data movement algorithms in magnetic bubble memories.

University of Illinois-Urbana; Franco P. Preparata; ***Parallel Computation and the Impact of VLSI***; (MCS-8105552); $36,022; 12 mos.

The principal topic of investigation is parallel computation. Two directions are explored:

1. Parallel computations
2. VLSI circuit design algorithms.

Parallel computation provides a fundamental answer to the need of increasing computer processing time. Technological advances have made it possible to realize parallel computing systems. Topics studied include the development of realistic computation models, the study of architectures realizable in the chosen models, and the analysis and design of algorithms executed on the chosen architectures.

VLSI circuit design algorithms are necessary in order for the full potential of VLSI to be realized. Effectiveness is realized through the development of layout algorithms which minimize chip area while complying with constraints imposed by VLSI circuit process technology.

Event based models of parallel computation are studied. Non-determinism in these models is expressed as a second order notion and the models are used to provide semantics for programming specification languages such as CSP.

Northeastern University; Robert J. Lechner; ***Harmonic Analysis of Logic Functions I: Encoded Programmable Logic Arrays***;

(MCS-8108685); $15,864; 12 mos. (Joint support with the Computer Systems Design Program-Total Grant $31,728).

This research is concerned with the development and evaluation of a new unified approach to array logic synthesis using VLSI technology on a scale which applies to software storage as well as to firmware storage and wired control logic within digital systems. Specifically PLAs are imbedded within linear encoding transformations on their inputs and outputs and combined with ROMS as necessary to define more optimal implementations of logic functions or stored tables than are possible with either ROMS or simple PLAs alone. In contrast to more general array logic techniques, the imbedded PLA approach retains the homogeneous array device layout and interconnection topology that reduces design and testing costs.

Heuristic algorithms are developed and tested on realistic examples to evaluate the feasability of the imbedded PLA approach. Theoretical studies are used to evaluate a more rigorous approach to canonical synthesis algorithms that do not require human intervention. A crucial outcome of the study is the identification of that class of functions for which the hybrid (ROM + imbedded PLA) approach to synthesis is more cost-effective than either ROMS or PLAs alone.

University of Michigan; William C. Rounds; *Formal Semantics of Distributed Computation*; (MCS-8102286); $22,645; 12 mos.

Event based models of parallel computation are studied. Non-determinism in these models is expressed as a second order notion and the models are used to provide semantics for programming specification languages such as CSP.

State University of New York-Albany; Richard E. Stearns; *Theory for the Design and Use of Concurrent Database Systems*; (MCS-7903770 A01); $25,000; 24 mos. (Joint support with the Special Projects Program-Total Grant $51,788).

Concurrency controls for database systems will be studied. Both centralized and distributed systems will be considered with the main emphasis on distributed systems. One objective is to produce concurrency controls which are proven to work correctly and which allow as much concurrency as possible. A second objective is to develop theoretical models which capture the essence of the real problems. The theory will be directed toward establishing the fundamental limits of concurrent operation and toward creating designs which have maximum flexibility within these limits.

An investigation will be made into the possibilities of controlling concurrency at the database manager level instead of the physical database level. The relational model will be given special attention because of the highly structured nature of the data model and the query languages.

Work will be continued on a database system simulator capable of simulating proposed concurrency controls under various load conditions. The simulator will be used to evaluate the relative merits of different designs.

Carnegie-Mellon University; H.T. Kung and Robert Sproull; *Conference on VLSI Design: Theory and Practice at Carnegie-Mellon University, September, 1981*; (MCS-8008165); $1,606; 12 mos. (Joint support with Computer Systems Design Program and Computer Engineering Program-Total Grant $4,818).

H.T. Kung and Robert Sproull will hold a two and one half day conference at Carnegie-Mellon University in October, 1981. The conference will be focused on VLSI chip design. The presentations at the conference will include a half dozen invited talks and contributed papers. Both theoretical and practical aspects of chip design will be stressed.

Carnegie-Mellon University; H.T. Kung; *Parallel Processing and Computional Complexity*; (MCS-7823678 A03); $74,881; 12 mos.

The research consists of two parts. The first one deals with developing fast parallel algorithms for such problems as garbage collection, game tree searching and parallel database organization. The communication complexity of parallel algorithms is also to be studied. The second part deals with analytic complexity. Information theoretic algorithms will be studied. The distance between these algorithms and optimal algorithms will also be studied.

University of Virginia; John L. Pfaltz; *Analysis of Multi-Attribute Retrieval Using Indexed Descriptor Files*; (MCS-8017779); $35,000; 24 mos. (Joint support with the Special Projects Program-Total Grant $75,000).

The investigator will concentrate on the problem of effective multi-attribute access in very large data bases, using "indexed-descriptor files". This technology has been shown to be comparable to binary

tree (B-tree) and/or inverted files access in relatively static data bases; but with much more flexibility, and, in the case of inverted file organization, with lower storage overhead. However, its performance, in terms of retrieval and storage costs, in dynamic systems is not well understood. This is particularly true since its very flexibility introduces many independent parameters. Implementation and analysis of a dynamic access system is the primary goal of the project.

## Abstract Complexity

University of California-Berkeley; Manuel Blum; *Complexity Theory and the Study of Automata in Two and Three Dimensional Space*; (MCS-7903767 A02); $42,000; 12 mos.

The research pertains to the study of the interaction between simple computers and their environment. The model provides considerable insight into the complex "intelligent" behavior of simple machines in a complex environment. The model has appeared independently in the works of several researchers (including this author) in this country and in Europe, and a rich body of theorems seems just now to be emerging. The expected output of this research should be useful results in the form of interesting algorithms and theoretical insight.

Wesleyan University; Kevin J. Compton; *Computational Complexity of Asymptotic Probabilities*; (MCS-8105211); $8,794; 12 mos.

The space and time requirements of machines that compute asymptotic probabilities are studied. The technique used in this study is to express the asymptotic probability computation as a statement in first or second order logic. The computational complexity of the proof of the statement is then related to the computational complexity of the asymptotic probability computation.

Yale University; Dana C. Angluin; *Algorithms for Inductive Inference*; (MCS-8002447 A01); $16,583; 24 mos.

The research is in the area of algorithms for inductive inference. The questions would be focused on:

1. formal analysis of heuristics,
2. special classes of languages of functions that are efficiently inferrable,
3. inference from finite sets with no knowledge of nonmembers,
4. state characterization of inference, and
5. a criteria of simplicity.

Yale University; Michael J. Fischer; *Advanced Computing Structures*; (MCS-8116678); $62,794; 12 mos.

The investigator will develop theory in several practical areas of computing. Goals are to find good abstract models, improved and inherent limitations. Particular topics to be studied include communicating processes, very large scale integrated circuits (VLSI), text editing, and time and space requirements of natural problems.

Purdue University; Carl Smith; *Workshop on Recursion Theoretic Aspects of Computer Science at Purdue University during May 1981*; (MCS-8007360 A01); $906; 18 mos.

The notion of effective computability is central to theoretical computer science and the techniques of recursive function theory have yielded important results. To review the status of this field a conference on the applications of recursion theory to computer science will be held at Purdue University during May 1981. The purpose is to provide a forum for computer scientists who use the techniques of recursion theory in their work and to promote interaction between such computer scientists and recursion theorists whose work is more purely mathematical in orientation. Approximately thirty to forty participants will meet and there will be ten invited speakers.

Purdue University; Carl Smith; *Automatic Program Synthesis*; (MCS-7903912 A01); $10,785; 12 mos.

Automatic program synthesis is studied from the viewpoint of inductive inference machines (IIMs). In particular, parallel computations using IIMs are studied. It has been determined that the expressive power of IIMs increases as additional IIMs are added. This phenomena is further studied with the aim of both determining the power of collections of IIMs and with investigating possible philosophical implications.

Boston University; Leonid A. Levin; *Algorithmic Complexity Theory and Applications*; (MCS-8104211); $34,955; 24 mos.

This project is concerned with the applications of algorithmic complexity theory. Applications will

be in the areas of computational complexity, foundations of probability theory, information theory, and inductive inference.

Rutgers University; Martin Dowd; *High Level Complexity Theory*; (MCS-8019004); $20,912; 24 mos.

The research concerns two topics.

1. Subrecursive many-one degrees.
2. Propositional representation of arithmetic proofs.

The first area involves the development of analogs of tools from recursive function theory for subrecursive complexity classes and reducibilities. Since such functions include all the "practical" functions, the study is particularly useful for obtaining reasonable analogs of the abstract recursive function theory results. The second area involves the restatement of arithmetic problems within a propositional proof system. Tools of proof theory can then be used to attack arithmetic problems.

Cornell University; Peter A. Fejer; *Recursion Theory*; (MCS-8103451); $9,800; 24 mos.

This project continues research done under NSF grant MCS-8017150 and deals primarily with the structure of the recursively enumerable (r.e.) degrees. A set of natural numbers is called recursively enumerable if there is an effective procedure for listing its elements. These sets arise naturally in many branches of mathematics. The class of r.e. sets is ordered by saying that A is below B if B is more complex than A, i.e., if A can be computed effectively from B. From this ordering, equally complex r.e. sets can grouped together into r.e. degrees, and the r.e. degrees inherit an ordering from that of the r.e. sets. The algebraic structure of the r.e. degrees is surprisingly rich, and many of its properties are not yet known.

The principal investigator will study an important class of r.e. degrees, the branching degrees, to see where they are located in the r.e. degrees as a whole and will consider whether certain algebraically interesting types of subsets of the r.e. degrees can be defined using only the ordering. He will also consider applications of recursion theory to other areas of mathematics.

State University of New York-Buffalo; John Case; *Machine Theory of Program Structure, Self-Reflection, and Inductive Inference*; (MCS-8010728); $58,921; 24 mos.

This project involves research in the general area of self-reflective control structures. Specifically, the following are being investigated:

1. The relative expressive power of control and data structures in universal programming systems.
2. The power and efficiency of self-reflective control structures.
3. Tradeoffs and characterizations of inductive inference machines.
4. New theoretical models of computation exhibiting the dichotomy between local-sequential control and global-parallel control.

The research will be performed at Yale University, New York University, and the State University of New York-Buffalo.

University of Pittsburgh; Robert P. Daley; *Axiomatic Computational Complexity and its Relation to Inference Problems and the Theory of Computation*; (MCS-8017332); $55,014; 24 mos.

The research concerns four areas of computer science all involving busy beaver sets. The kth busy beaver number is the largest number computed by any program of k statements with input O. A busy beaver set is the set of all busy beaver numbers. The four areas of research are:

1. The relation between complexity and inference;
2. The simplification of existing constructions in the theory of computation via computational complexity notions as well as the development of new results;
3. Construction of a busy beaver analog for concrete complexity classes together with the simplification of constructions dealing with these classes;
4. The use of busy beaver sets in model theoretic constructions to ascertain provability of various concrete complexity statements within particular formal logical theories;

University of Washington; Richard E. Ladner; *Theory of Advanced Computing Structures*; (MCS-8003337 A01); $46,772; 12 mos.

The investigators will develop theory in several practical areas of computing. Goals are to find good abstract models, improved methods, and inherent limitations. Particular topics to be studied include

communicating processes, very large scale integrated circuits (VLSI), text editing, and time and space requirements of natural problems.

The work has three main objectives: constructing formal models, finding improved methods, and discovering inherent limitations.

## Foundations of Computer Science

Stanford University; Zohar Manna; ***Temporal Verification and Synthesis of Concurrent Programs***; (MCS-8111586); $44,492; 12 mos.

Temporal Logic has been found to be a useful and powerful formalism for the analysis of concurrent programs. It is proposed to continue research aiming at developing the temporal methodology into a practical verification and synthesis tool. The ultimate goal is to construct an experimental Temporal Logic verifier for concurrent programs, and to establish a temporally based methodology for synthesis of concurrent programs.

Stanford University; John McCarthy; ***An Application of Proof Theory to Computing***; (MCS-8104873); $73,348; 24 mos.

Work in proof theory has shown that a proof of a formula of the form "for all x there is a y such that R(x,y)" can serve as a description of an algorithm A which satisfies the specification R in the sense that "for all x, R(x,A(x))" holds. Such a proof contains more data about the algorithm which it describes than does an ordinary program, and this data is useful for the automatic transformation of the algorithm. We investigate the use of proofs as descriptions of algorithms, with the aim of developing an improved technology for transforming algorithms.

University of California-Berkeley; Michael A Harrison; ***Cryptography and Theory of Computation***; (MCS-8012716 A01); $82,217; 12 mos.

This investigation will bring together a number of disciplines and people and the major funding would bring researchers to Berkeley for the summer. The common ground of the investigations is in modern communication and complexity theories. The research is into the analysis and application of cryptosystems using complexity theory and probabilistic algorithms. Related problems of a graph theoretic nature will be considered. Other questions that will be investigated are rational best approximations of the second type to a vector of real numbers of the second type, nondeterministic polynomial approximation problems, and combinatorial properties of matrices. Another area will be concurrent programs and large data structures.

University of California-Berkeley; Lofti A Zadeh; ***A Theory of Approximate Reasoning***; (MCS-7906543 A02); $15,750; 12 mos (Joint support with the Division of Information Science & Technology-Total Grant, $31,500).

This research is aimed at the development of a method of inference from imprecise or unreliable data which are expressed in the form of propositions in a natural or synthetic language. The main application areas for this method lie in the design of expert question-answering systems, decision analysis, and control of robotic systems operating in an imprecisely defined environment.

The approach of this research is based on the representation of the meaning of an imprecise proposition by a procedure which acts on a set of relations in a database and returns a possibility distribution for the variables which are associated with the proposition. The inference rules are applied to the translation of the premises and yield a possibility distribution which upon retranslation becomes an imprecise conclusion inferred from the premises. In general, the premises are allowed to be qualified with imprecisely defined truth values, probability values or possibility values.

University of Colorado-Boulder; Andrzej Ehrenfeucht; ***New Directions in Mathematical Theory of Languages***; (MCS-7904838 A01); $37,485; 24 mos.

The following areas are investigated:

1. Combinatorial properties of rewriting systems,
2. Deterministic production systems,
3. Selective substituting grammars,
4. Graph grammars, and
5. The post correspondence problem.

Georgia Institute of Technology; Richard A. DeMillo, Kimberly N. King, and Raymond Miller; ***Models of Computation and Algorithms***; (MCS-8103608); $86,986; 12 mos.

Theoretical research will be performed on models of computation. In the area of parallel models

and concurrency, two projects will be undertaken; one project introduces the notion of stochastic synchronization and will clarify properties of contention-based synchronization, while the other project is a comparative study of models of parallel computation. In the area of more conventional models a number of problems are addressed: computational complexity of alternating machines, logical independence, VLSI algorithms, and combinatorial graph embeddings.

University of Chicago; Irving Kaplansky; ***Groups, Rings, and Homological Algebra***; (MCS-7904469 A04); $4,120; 12 mos. (Joint support with the Special Projects Program-Total Grant $5,020).

This award represents a supplement to MCS-7904469 for the partial support of the visit of Professor Michel Broue.

Broue has recently discovered an extensive analogy between the Deligne-Lusztig theory of representations of finite groups of Lie type and the theory of subpairs in block theory. He intends to pursue the ideas suggested by this analogy. It is expected that there will be extensive opportunity to collaborate with J. Alperin and other mathematicians in the Chicago area during the visit.

Massachusetts Institute of Technology; Albert R. Meyer; ***Logic of Programs and Computational Complexity***; (MCS-8010707 A01); $109,184; 12 mos.

The relations among several programming logics in the literature are considered and a study of their comparative expressive power is undertaken. These Logics include Dynamic Logic (Pratt), Algorithmic Logic (Engeler), Algorithmic Logic (Salwicki), Programming Logic (Constable), and Logic of Effective Definitions (Tiuryn). In computational complexity the investigators will consider the relation between the geometry and accessibility of memory structure, and speed of computation.

Tufts University; Neil Immerman; ***First Order Expressibility as a Measure of Computational Complexity***; (MCS-8105754); $27,567; 24 mos.

A new method of investigating computational complexity is explored. The method uses the length of sentences in first order logic as its complexity measure. A previous result showed that the length of a sentence that checks a condition is within a square of the length of a sentence required to state the condition. These results translate directly to the more traditional approaches used in considering computational complexity clauses.

The topics being investigated include a search for optimal first order descriptions of combinatorial conditions and the efficiency of expressibility from the point of view of classical mathematical logic.

Rutgers University; Ann Yasuhara; ***Computability on Term Algebras***; (MCS-8009534 A01); $19,572; 12 mos.

The principal investigator is investigating effective methods of computation on finitely generated free (term) algebras that are to be analogous, in each case, to the effective computations on the natural numbers determined by the partial recursive functions. For each case a finitely axiomatizable theory will be found that is just strong enough to represent the class of functions on the particular term algebra computed by the method. Within each such class of functions the investigator wishes to delineate certain subclasses and to relate the various classes to one another in terms of complexity. In terms of the setting thus established the investigator also will consider further work in connection with recursive function theory, logic, finitely presented algebras as congruence classes, relative complexity in terms of coding, and abstract data types.

City University of New York-Brooklyn College; Kenneth McAloon; ***Arithmetic Theories and Incompleteness Phenomena***; (MCS-8102854); $24,534; 24 mos. (Joint support with Topology, Geometry, & Foundations Program-Total Grant $34,534).

The research is in the areas of theoretical computer science and mathematical logic. The problems studied include:

1. Phenomena of mathematical incompleteness in arithmetic
2. The proof theory and model theory of weak systems of arithmetic and applications of those results to the provability of equality of complexity classes.
3. The complexity of decision procedures and the rates of growth of recursive functions.

Cornell University; Robert L. Constable and Alan J. Demers; ***On Logics for Program Development***; (MCS-8003349); $50,000; 12 mos. (Joint support with the Software Engineering Program and Software Systems Science Program-Total Grant $173,705).

This research involves the judicious combination of the strong points of program development method-

ology and program verification in a logic for correct program development. This project will explore a logic of formal top down development, called a refinement logic. During the grant period a prototype system will be designed and built. This system will be used in extensive experimentation of the refinement logic concept. Comparisons with other systems will also be conducted.

International Business Machines Corporation; Dexter C. Kozen; ***Workshop on Logics of Programs to be held at the IBM Thomas J. Watson Research Center in Yorktown Heights, New York in April 1981***; (MCS-8019346); $9,353; 12 mos.

The workshop will bring together the proponents of the various logics of programs (Dynamic Logic, Temporal Logic, Programming Logic, Algorithm Logic, Process Logic and Logic of Effective Definitions). Besides the presentation of papers, there will be discussions in which issues of mutual concern will be resolved.

There will be approximately 18 talks by invited participants only. A proceedings will be published. Approximately 18 participants will be invited.

New York University; Martin Davis; ***Logical Investigations in Computer Science***; (MCS-8002438 A01); $30,230; 12 mos.

Methods of logic play a continuing role in computer science. A central problem in the complexity of algorithms is the problem of determining whether certain Boolean expressions can be given the value "true" by substitutions for the variables. Although this problem is believed to be "intractable," recent work has suggested that improved algorithms for this problem can be constructed by patching together algorithms each of which works well on appropriate cases. Work on the representation of the sets of inputs "accepted" by various automata by corresponding equations in natural numbers will also be worked on. That such representation is possible in general is now well known from the solution of Hilbert's famous tenth problem but little is known about the specific equations that result when restrictions are placed on the automata. Recently introduced coding methods will be used to shed light on this.

## Automata and Language-based Models

University of California-Santa Barbara; Ronald V. Book; ***Computational Complexity and Formal Languages***; (MCS-8011979 A01 & A03); $38,459; 12 mos.

The goal of this research is to investigate questions in automata based complexity, the representation of complexity classes in terms of language theoretic characteristics, and the classification of functions and predicates by the complexity of their syntactic definitions.

Tools and techniques from the theory of formal languages will be appled to problems in computational complexity, while tools and techniques from the area of computational complexity will be applied to the theory of formal languages.

This grant includes support for one summer for Professor Donald H. Potts, California State University-Northridge.

Univeristy of California-Santa Barbara; Ronald V. Book and Craig Squier; ***Algorithmic Problems in Group and Semigroups***; (MCS-8116327); $14,015; 12 mos.

Certain problems about finitely presented groups and semigroups will be studied to determine whether they are decidable and, if so, whether their intrinsic computational difficulty can be determined.

The role of the Church-Rosser property for presentations will be investigated. The question of whether a property is computationally less difficult to decide for semigroups than for groups will be studied. This research has applications to both algebra and complexity theories.

Northwestern University; Ivan H. Sudborough; ***Applications of Automata Theory to Computational Complexity***; (MCS-8109280); $64,653; 24 mos.

The research is concerned with the relationship between the complexity of combinatorial problems and various forms of layout complexity, such as bandwidth, minimum cut, optimal linear arrangement and separation. This work will:

1. provide new algorithms for various natural combinatorial problems of interest to practitioners.
2. develop further information about the the relationships between complexity classes.
3. unify the study of the multitude of complexity classes currently under investigation by demonstrating their similarities.

In addition to the research includes topics in traditional forms of automata theory and its appli-

cation to computational complexity (e.g. the power of nondeterminism, alternation, and unbounded pushdown store) and topics in concrete complexity.

Rutgers University; Richard Statman; ***Syntax and Semantics of the Typed Lambda-Calculus***; (MCS-7923199 A01); $18,972; 24 mos.

The typed lambda-calculus is investigated for its application as a tool for formal deduction-particularly deductions associated with the semantics of programming languages. The principle question studied is the lambda-definability conjecture which asks the decidability of determining whether a functional defined over a finite base domain is the interpretation of a closed lambda-term. Results obtained by studying this question also have application to the problem of determining the complexity of first-order theorem proving algorithms.

State University of New York-Buffalo; Eitan M. Gurari; ***Complexity of Decision Problems***; (MCS-8021124 A01); $49,173; 24 mos.

The complexity of various decision problems is investigated. In particular, the objectives of the work are: to pinpoint the boundary between solvability and unsolvability of decision problems for simple programming languages, transducers, and digital image processing; to obtain sharp complexity results for those problems that are solvable; and to look for additional applications to ideas and results that were introduced recently for deriving the complexity of decision problems.

University of Oregon; Patrick Shen-pei Wang; ***Towards a Theory of Sequential/Parallel Matrix Array Languages***; (MCS-8003290); $28,961; 24 mos.

A new system called sequential/parallel matrix grammar for two-dimensional pattern processing is introduced and studied. Various language operations such as union, catenation (row and column), Kleene's closure (row and column) and substitutions are investigated. The equivalence of sequential/parallel matrix languages and their recognition counterparts is established. Hierarchies for both languages and recognizers are also found. We also give regular-like expressions and array grammars that describe sets of matrix patterns or rectangular arrays with fixed proportions. Several related future research topics such as computational complexities, decidability problems, efficiency of recognizers and abstract family of matrix patterns are proposed.

The main goal of this research proposal is to establish a theory of sequential/parallel matrix array languages, which provide a compromise between purely sequential methods that take too much time for large arrays and purely parallel methods that usually take too much hardware for large arrays.

# Software Systems Science

## Programming Languages and Compilers

University of California-Berkeley; Susan L. Graham; ***Programming Language Implementation***; (MCS-8005144 A01); $66,375; 12 mos.

The project will comprise both a continuation of ongoing research and an initiation of new investigations pertaining to interactive programming environments. The study of techniques for producing portable compilers; in particular, the development of table-driven methods for the synthetic (i.e., code-generation) phase of compilation will be continued. The table-driven algorithm will be embedded in a complete compiler, both in order to test the feasibility of the technique as a practical tool and to compare it with other designs for retargetable compilers. The LR error recovery technique in the Pascal compiler will be compared with the methods recently developed by other researchers. The compiler technology that has been developed will also be extended to the design of other programming tools, such as editors, debuggers, and program transformation systems. The goal is to facilitate the production of source-language-knowledgeable tools which take their language knowledge from a data base that can be changed readily, thereby "porting" the tool to another source language while maintaining a familar user interface. Finally, some of the particular problems that arise in the implementation of the recently announced programming language Ada will be in-investigated.

University of Southern California; Robert M. Balzer and David Wile; ***Supervisory Control of Transformational Implementation Systems***; (MCS-7918792 A01); $109,125; 12 mos. (Joint support with the Software Engineering Program-Total Grant $218,250).

This project is aimed at the long-term development of Transformational Implementation Systems. The work falls into two categories, systems building and fundamental research. The systems building activity provides essential support as a means of building an experience base for developing the insights and perceptions which guide the research and as an experimental vehicle for testing ideas and hypotheses.

The ultimate system is presently seen as having five sets of facilities:

1. facilities to impose a structure on transformation selection and application, involving planning subsystems, documentation subsystems and maintenance subsystems.
2. facilities to prove applicability criteria of properties of transformations. Transformations may be applied before some properties are proved applicable necessitating subsequent proof of such properties by inference or symbolic execution or via a general purpose theorem prover or a special purpose property prover.
3. facilities to do automatic program simplification and to provide automatic application of low level transformations that seek canonical forms.
4. facilities for combining individual transformations into layer coordinated packages.
5. facilities to generate new transformations for the catalog on the basis of interactive user editing of the state of the program being generated.

Colorado State University; Robert A. Mueller; ***Specification and Automated Synthesis of Micro-Code***; (MCS-8107481); $61,380; 24 mos.

This work addresses the problem of automating the production of reliable micro-code. In contrast to validation and verification approaches which attempt to establish the correctness (incorrectness) of manually produced code with respect to a set of specifications, the automated synthesis approach attempts to systematically derive the code directly from the specifications.

Formal schemas for specification of both host microprogrammable machines and image instruction sets are required, as is a formal semantic characterization of microprogram execution with respect to specification constraints. The microprogram synthesis process can be viewed as a special kind of theorem proving process which attempts to establish the existence of a microprogram computation which satisfies requirement specifications.. When successful, a corresponding microprogram can be

extracted directly from the proof. Effective heuristics play a crucial role in the process.

Yale University; Joseph A. Fisher; ***The Extension and Application of Global Compaction Techniques for Horizontal Scientific Code***; (MCS-8107646); $94,599; 24 mos.

This research will build upon work already done in the area of global code compaction for very wide instruction, parallel functional unit computers (typified by horizontally microprogrammable CPUs and scientific attached processors). A method called "trace scheduling" to compact programs with a general control flow has been developed. Trace scheduling has the potential for significantly better compactions than earlier methods.

The project will investigate some extensions to trace scheduling and implement solutions. Topics include: Binding various abstract language constructs to concrete machine resources at compaction time; A novel technique for compacting critical loops using an extension of trace scheduling.

Illinois Institute of Technology; Thomas W. Christopher and Martha W. Evens; ***Distributed Compilers for Distributed Systems***; (MCS-8004144 A01); $78,465; 12 mos.

The proliferation of distributed computing systems has brought about a new kind of software crisis. The development of distributed hardware has far outstripped the development of the necessary software. There is a strong need for compilers which translate high level languages into machine code. To make distributed computing systems self-sufficient such compilers must both run on a distributed system and generate code for that same system. The development of such compilers presents two novel problems: how to organize the compiler itself into small modules that run in parallel and how to partition the code into clusters of tasks small enough to fit into the separate computers of the distributed system. This project will carry out research on the problems of distributed compilers for distributed systems: the problem of distributed compiler organization and the problem of distributed code generation. This research will consist of three parts: a theoretical attack on the code partitioning problem, evaluation techniques to compare various partitioning methods, and actual development of distributed compilers for high level languages.

University of Illinois-Urbana; David J. Kuck and Duncan H. Lawrie; ***Software Studies for Parallel Memories, Multiprocessors, and Virtual Memories***; (MCS-8100512); $114,250; 12 mos.

This project is an attempt to bridge a gap between a programmer, organizing his problem sequentially, and computers with modern architectural features that provide the potential advantage of considerable parallelism. Program transformations (optimizations) which take programs written naively in ordinary computer languages and compile them into code taking advantage of given architectural features have been developed. A broader class of architectural features including virtual memory and cache memory is now being considered. Several types of multiprocessors, including various data flow proposals are also to be considered.

A compiler can take advantage of a great deal of information that is available in a source program to map the program onto some computer structure. In particular, much remains to be learned about source language (or precompiler) optimization.

Purdue University; Michael J. O'Donnell and Christoph Hoffmann; ***A Uniform Theory for Implementations of Descriptive Languages***; (MCS-7801812 A01); $160,659; 24 mos.

Machine interpretation and compilation of programs expressed in procedural languages is fairly straightforward. But describing the task of converting an intuitively understandable problem statement into a procedure suitable for computation, that is the semantics, remains difficult and poorly understood. By contrast, descriptive languages such as LISP, Lucid, PROLOG and recursive equation schemata are difficult to implement; existing implementations usually are interpretive.

This project will investigate uniform methods for mechanically generating efficient interpreters and compilers for a broad class of languages including those mentioned above. Theoretical results on reduction sequences to automatically generate efficient interpreters will be used. In addition, these theoretical results will be extended to cover more general language specifications and to answer more subtle questions about the relative efficiency of interpretive strategies.

Cornell University; Alan J. Demers and James E. Donahue; ***Verifying And Implementing Russell***; (MCS-7901048 A01); $88,897; 24 mos.

This project is directed toward the completion of the Russell language, the design of which is based

on the semantic notion of "strong typing." The proof that Russell is strongly typed will be a statement of the correctness of the type checking rules. It is expected that the entire language can be defined by algebraic axioms. This form of definition will be completed as an exploration of the use of equational specifications as a programming logic. Existing implementations of Russell are not efficient. The completion of the project will include a more efficient implementation of the language.

New York University; Jacob T. Schwartz; ***Optimization of Very High Level Languages***; (MCS-8004349 A01); $85,000; 12 mos.

Building on the success of the present global analysis and data-structure choice algorithms of the SETL system, these techniques will be extended to three related areas:

1. Application of global analysis techniques to improved static methods of program debugging;
2. Development of a partially extensible optimizer, able to handle user-defined object types in terms of their logical significance rather than their internal structure;
3. Automatic choice of data structures from a broader range of possibilities, including high-efficiency use of lists and B-trees.

University of Rochester; Jerome Feldman; ***Distributed Computing Research***; (MCS-8104008); $200,000; 24 mos.

Computer networks are playing an increasingly important role. The early research on computer networks as communication media is being put into practice, but much remains to be learned about distributed computation—the use of several computers to accomplish a specific task. At the University of Rochester, a variety of aspects of this problem have been under investigation for several years. The current project will pursue work on distributed operating systems, high-level languages, and on formal analysis and synthesis techniques. In each area, past results of proven utility form the basis for research on new problems.

The distributed operating system portion concentrates on job management, debugging, and file systems. The language portion attacks data representation and encapsulation. Proof techniques and performance enhancement are also areas of current effort.

Syracuse University; F. Lockwood Morris; ***Very High-Level Statically Typed Programming Languages***; (MCS-8100513); $42,185; 24 mos.

This project will investigate the implications for the design of very high-level programming languages of a certain notion of types. This notion permits complete compile-time type checking by an efficient unification-based algorithm; frees the user in principle from the necessity of writing any type information in his program (the typing algorithm being even capable of automatically inducing recursive data type definitions); and allows functional polymorphism. Research activities will include providing a mathematical foundation for the system of types, improving the design of an exemplary language employing the type system, and studying implementation problems of this and related languages.

University of Pittsburgh; Mary L. Soffa; ***Control Implementation in Programming Languages***; (MCS-7906102 A01); $46,634; 24 mos.

Advanced control structures which permit the expression of complex algorithms are being proposed and incorporated into programming languages today. A number of implementation schemes have been designed for the retentive forms of control. It is unclear what implications these implementation strategies have on the control forms or the effect the control forms have on the implementation schemes. This project will address issues in control implementation and control semantic specification. The specific objectives include experimentation in control form design and implementation and the development of an axiomatic specification technique for control semantics which would be of value to the implementor. This work would be a first step toward a system which automatically selects the best control implementation strategy on an individual program basis as determined by control usage and programming style. Other anticipated benefits include: the development of a software tool useful in language design implementation; comparison of various implementation strategies; the derivation of important properties of control implementation using an axiomatic specification of control semantics; and the investigation into the usefulness of a system in which the user has some control in the implementation.

Rice University; Robert S. Cartwright; ***Specification Languages to Support Program Verification, Testing, and Translation***; (MCS-8104209); $83,438; 24 mos.

The design of abstract, very high level specification languages is a promising research area that could profoundly influence program verification, testing, and translation. Conventional specification languages (Boolean program expressions plus quantifiers) are so cumbersome that annotating production programs is an arduous task.

In this research project, we intend to develop a rich, very high level specification language specifically designed to simplify the task of annotating programs written in production languages such as Pascal, C, FORTRAN, AND PL/I. In conjunction with designing this language, we intend to explore how program debuggers and translators can exploit program annotation.

We are particularly interested in investigating less ambitious alternatives to program verification such as formal program testing. A formal program testing system is similar to a program verification system, except that verification conditions are tested rather than proved. The testing system evaluates each verification condition on a set of heuristically generated (with programmer guidance) test values.

Rice University; Kenneth W. Kennedy; ***An Optimizing Program Management System for Vector Fortran***; (MCS-8104006); $118,860; 24 mos.

To effectively use parallel computers, languages are needed which permit the specification of parallel algorithms. However, compilation of such languages presents special problems. Because the fundamental operations may involve large data structures such as arrays, careful optimization is essential if the generated object programs are to be acceptably efficient. Furthermore, since these large data structures are routinely passed back and forth between subroutines, the inefficiencies arising from separately compiled subroutines take on increased importance.

This project would experimentally investigate optimization techniques for a version of FORTRAN extended to include a powerful notation for specifying vector and array operations. The main tool will be a compiler that is currently used to study FORTRAN optimization, which will be converted to accept the extended language. The compiler will be enhanced by embedding it in a program maintenance system that will manage all the source and object modules comprising a program and maintain a data base of interprocedural information which can be used to optimize individual modules. By managing the whole program, the substantial efficiency penalty paid to achieve separate compilation is expected to be overcome. Results of this work should also be applicable to the compilation of APL and Ada.

University of Virginia; Terrence W. Pratt; ***A Formal Theory of Programming Language Definition***; (MCS-7800763 A02); $10,828; 0 mos.

A complete formal theory of programming language definition has been developed and brought to maturity under partial NSF support over the past nine years. Work in the past year has shown that the methods developed provide excellent tools for design, definition, and analysis of languages, and that the definitions can be directly used as implementation specifications. This research project will be continued for two major purposes: (1) to provide for publication of information on the methods and their use to a wide audience, and (2) to support a first effort into the use of these methods for the specification and analysis of the semantics of languages and systems for parallel computations on multiprocessor systems. Related work into the use of the methods for specification of data base systems and for further development of techniques for the formal analysis of language definitions will also be pursued.

## Operating Systems

University of Massachusetts; John A. Stankovic; ***Decentralized Control of Job and Process Scheduling in Distributed Processing Systems***; (MCS-8104203); $38,799; 24 mos.

This research concentrates on a specific class of distributed processing systems that are in the early research stage. These systems are characterized by decentralized system-wide control of resources for the cooperative execution of application programs. Moreover, these systems must operate with missing, incomplete, or erroneous state information. Specifically, the primary research effort is to develop, compare and evaluate job and process scheduling algorithms for such a noisy environment. The approach includes the use of Bayesian Decision Theory. The potential advantages of this research are to reduce the cost of maintaining centralized control of a distributed system, eliminate critical entities (resources), and provide better overall performance. Furthermore, due to the elimination of critical resources and the development of algorithms that can operate in the presence of missing or erroneous data, improved reliability may also be possible.

## Data Base Systems

Harvard University; Philip A. Bernstein and Nathan Goodman; ***Frameworks for Database System Implementation Problems***; (MCS-7907762 A01); $109,450; 24 mos.

This project addresses three problems of database systems (DBMS) implementation: semantic integrity, concurrency control, and query processing. The main tactic for studying these problems is the mathematical analysis of formal models of DBMS components. New formal models will be developed and old ones will be extended to concisely present all known solutions to these three problems. In the long term, this work will help systematize and simplify the process of designing DBMS's.

Rutgers University; Gilles Lafue; ***Automatic Checking of Semantic Integrity in Design Databases***; (MCS-8110100); $45,091; 24 mos.

The purpose of this project is to design a subsystem for automatically checking the semantic integrity of databases. The major cost of integrity checking is caused by the number of records to access at every database update, in order to check whether or not some semantic integrity constraints are violated as a result of the update. The subsystem will re-distribute this cost by checking integrity in parallel with applications, and by eliminating needless integrity checking. It is also believed to be a good model of some "real world" types of interaction with databases, especially for design databases, i.e., databases used as support of design activities. Checking the integrity of such databases is a particular challenge, due to the relatively high frequency of their updates. The basic idea is to check integrity only when strictly necessary, that is, only for the records in the current focus of attention, tolerating temporary integrity violations by records outside this focus. This is supported by a mechanism to "remember" the causes of potential violations in the records whose integrity checking has been delayed. The notion underneath this approach is that the responsibility for the violation of an integrity constraint is not always equally shared by all the records involved in this constraint.

## Formal Structure of Programs

Stanford University; Donald E. Knuth; ***Analysis of Algorithms***; (MCS-7723738 A03); $194,429; 12 mos.

The present program of research in the Analysis of Algorithms will be continued. The research is oriented toward an improved quantitative understanding of the fundamental algorithms of computer science, and it comprises five major activities:

1. Development of new, efficient methods for use on computers;
2. Analysis of the performance of important computer techniques;
3. Analysis of the computational complexity of problems;
4. Studies of programming languages; and
5. Combinatorial theory to support the above activities.

Stanford University; Zohar Manna; ***A Deductive Approach to Program Synthesis***; (MCS-7909495 A01); $66,637; 12 mos.

Program synthesis is the systematic derivation of a program from given specifications. This specification constitutes a high-level description of the desired program which expresses the purpose of the program, without indicating the method by which that purpose is to be achieved. A deductive approach to program synthesis will be used for the construction of recursive programs. Such an approach regards program synthesis as a theorem-proving task and relies on a theorem-proving method that combines the features of transformation rules, unification, and mathematical induction within a single framework.

This project will focus on:

1. Development of subsidiary procedures; construct systems of procedures that form together the desired recursive program.
2. Generalization of programs; extend the given specification to represent a more general problem that is, nevertheless, easier to solve.
3. Construction of program with side effects; construct programs that can change the values of variables and manipulate other data structures.

Indiana University; Mitchell Wand and Daniel P. Friedman; ***Algebraic and Logical Semantics of Computation***; (MCS-7904183 A01); $172,437; 24 mos.

The introduction of formal techniques for proving that a program module meets its specifications

has been an important development in computer science. Such formal techniques must rely on a formal statement of specifications, expressed in a formal specification language. Although a number of different specification techniques have been proposed, none provides a unified logical theory comparable in breadth and depth to that of first-order predicate calculus. The goal of the research is the study of the logic of specific languages. This should shed light on the distinction between "implementation" and the conventional mathematical notion of a model.

Cornell University; David J. Gries and Fred B. Schneider; ***Programming Methodology***; (MCS-8103605); $107,617; 12 mos.

This research is concerned with advancing the science of computer programming, with respect to concurrent as well as sequential programs. Techniques for the development of provably correct and easily understood programs will be developed and used. A by-product will be more insight into how better to teach programming.

A major theme of this work is the axiomatic approach and use of weakest precondition predicate transformers in the derivation of programs and in the definition of programming constructs. Extension and application of this methodology to the design and implementation of large programming problems will demonstrate its utility for "programming-in-the-large. Extensions for designing fault-tolerant software as well as techniques for understanding concurrent programs and proving them correct, with emphasis on distributed programs, will be studied.

Both theoretical and practical issues will be explored. It is expected that new algorithms for old problems will be discovered. The discovery of new problems, their solutions, and paradigms for developing distributed programs is also anticipated. Among the initial problems to be attacked are: network routing protocols, decentralized algorithms for resource allocation, and synchronization.

Syracuse University; John C. Reynolds; ***The Design, Definition, and Implementation of Programming Languages***; (MCS-8017577); $59,405; 12 mos.

Research will be carried out on the design of programming languages and the mathematical definition of their semantics, with emphasis on the design of Algol-based languages and the use of category theory as a definitional tool. Specific topics include: the application of category-sorted algebras to treat implicit conversions and generic operators; the use of a non-functional Cartesian closed category to provide an abstract model of the store; extension and modelling of a language in which interference can be determined syntactically, and development of a variant of specification logic for proving programs in such a language; and models of languages with type binding.

North Carolina State University; Dana M. Latch and Donald F. Stanat; ***Semantics of Functional Programming Languages***; (MCS-8104217); $123,124; 24 mos. (Joint support with the Algebra & Number Theory Program-Total Grant $132,120).

Joint research, to be done equally in a collaborative effort at NCSU and UNC at Chapel Hill, will investigate alternative semantics for functional programming languages. Particular emphasis will be on developing mathematically rigorous semantics for a language that includes infinite sequences, or streams, in its domain of operands. This work is expected to include consideration of the treatment of error messages and the role of . Category theory will be used as the basis for exploring and characterizing the various semantics considered.

Carnegie Mellon University; Mary Shaw; ***Abstraction Techniques for Software Development***; (MCS-8011409); $141,318; 24 mos.

This project will continue research in programming methodology, and specifically investigation of new methods of abstraction for software development. This research is a continuation of a project that has produced results about abstract data types, the incorporation of specifications in programs, and verfication techniques; these ideas were brought together in a complete programming language, Alphard. In Alphard, we developed not only a programming language but also a related verification methodology for proving functional correctness.

We turn now to new abstraction techniques and methods for specifying the properties of abstractions. The shortcomings of current techniques suggest a number of research problems; we will begin by finding ways to specify properties of programs other than the direct effects they have on data values—that is, extra-functional properties—and ways to verify that such specifications are accurate.

Brown University; Robert Sedgewick; ***The Analysis and Implementation of Algorithms***; (MCS-8017579); $60,530; 24 mos.

(Joint support with the Theoretical Computer Science Program-Total Grant $121,059).

The research involves the precise mathematical analysis of the running times of a set of fundamental algorithms and their implementations on a variety of computer architectures. Exact closed form solutions for both actual running times and for expected running times are sought. Additionally, for algorithms that are particulary difficult to analyze, statistics on actual running times over large domains of inputs will be collected and curve fitting attempted. As a useful spinoff, the implementations best suited for particular environments will be identified.

## Concurrency

SRI International; Leslie Lamport; *The Specification and Verification of Concurrent Programs*; (MCS-8104459); $94,965; 12 mos.

A general method for the formal specification and verification of concurrent programs will be developed. Two current approaches, temporal logic and our generalization of Hoare's program logic, will be merged into a unifying logic for concurrent programs. This logic will permit reasoning about properties of a program without requiring its implementation to be described in terms of indivisible operations. It will encompass our current work on a fundamental theory of distributed concurrent systems.

The logic will be used as the basis for a hierarchical specification and verification methodology. In developing this methodology, we will formulate temporal logic techniques for specifying the semantics of sophisticated programming language features. The utility of the approach will be demonstrated by its application to several examples, including a hierarchical system of network protocols.

Stanford University; Susan S. Owicki and David C. Luckham; *Specification Methods for Parallel Programs*; (MCS-8015336); $63,423; 12 mos.

This project will investigate methods for specifying parallel programs, focusing attention on three important areas:

1. Formulation of requirements: study and precise formulation of properties required of parallel programs in practice,
2. Specification languages: design of high level languages in which the required properties may be stated easily, and
3. Methods of program specification: study of different kinds of specifications and how they constrain the various components of a parallel program; formulation of standards and methods of program documentation.

Harvard University; Edmund M. Clarke; *Design and Verification of Concurrent Systems*; (MCS-8105553); $127,300; 24 mos.

The rapid development of computer networks and multiprocessor systems has increased the need for methods of constructing reliable concurrent systems. This project is directed at improved understanding in three particularly important areas of concurrent system development:

1. Specification and verification of concurrent systems. Proof rules for liveness properties of concurrent programs are difficult to formulate because such properties lack continuous fixpoint characterizations. It may be possible to construct concurrent programs in which the synchronization skeleton is automatically synthesized from a high-level temporal logic specification.
2. Construction of distributed algorithms. Protocols, such as the distributed termination protocol, that can be superimposed over a distributed program to ensure some particular behaviour will be studied. Also, it may be possible to transform the specification of a sequential program into that of an equivalent distributed program.
3. Fault-tolerant computing. Multiple resources potentially enable a system to continue functioning despite hardware errors. Software to detect errors and to reconfigure the system into a reliable subsystem is required. A current line of research on such reconfiguration strategies will be extended.

Pennsylvania State University; David W. Wall; *Low-Delay Broadcast on Spanning Trees*; (MCS-8102278); $30,679; 24 mos.

Much of the work done on the effective use of distributed systems has assumed the existence of a broadcast mechanism for sending an identical message to every node in the network. One way of

providing such a facility is to consider the network to be a graph and impose some kind of spanning tree on that graph; broadcasts are then routed along the branches of this tree without redundant transmissions.

The cost of broadcasting can be minimized by making this tree a minimum spanning tree, but minimizing the delay is not possible unless we use a different tree for each broadcast source. The technique of center-based forwarding, which uses a single tree but for which good bounds on the delay can be proven, was developed in the author's thesis.

This work will be extended by considering various alternative approaches in an effort to improve these bounds, by investigating the problems of reliablity in such systems, and by examining questions of the specification and verification of distributed routing algorithms in general.

## Verification

SRI International;Robert E. Shostak; ***Mechanizing the Mathematics of Computer Program Analysis***; (MCS-7904081 A02); $70,217; 12 mos.

The present line of work has led to the development of an extensible formal theory for reasoning about the inductively constructed objects (e.g., integers and sequences) underlying the semantics of programs, and the development of an automatic theorem-prover for that theory. One measure of the success of the work to date is the list of difficult programs proved correct by the system: a simple optimizing expression-compiler, an expression-parser, a fast string-searching algorithm, a mechanical theorem-prover for propositional calculus, and an arithmetic simplifier. The deepest theorem proved thus far is the unique prime factorization theorem, which is derived entirely from the Peano axioms for integers and lists and previously proved theorems. Improvements to both the theory and the proof techniques will be pursued. These improvements will make it easier to state and prove many kinds of assertions (e.g., by providing recursive, schematic concepts), will ease the burden on the user during proofs (e.g., by mechanically inventing lemmas), and will increase the system's competence on many important domains (e.g., graphs, the rationals, combinatorics). The utility and feasibility of extending the system with subroutines proven sound by the system will be demonstrated.

University of Illinois-Urbana; David A. Plaisted and Nachum Dershowitz; ***Term-Rewriting Systems and Computer-Aided Deduction***; (MCS-7904897 A01); $134,830; 24 mos.

This project will continue an investigation of the verification and generation of programs expressed as sets of term-rewriting rules. The investigation will be extended to deduction and programming in the general first-order predicate calculus. Both term-rewriting systems and the first-order predicate calculus have a simple, elegant syntax and semantics, in contrast to conventional high-level programming languages. The termination, confluence, and partial correctness of term rewriting systems will be studied. Finally, generalizations of PROLOG for the first-order predicate calculus and the use of abstraction in guiding the search for a proof will be investigated.

Cornell University; Robert L. Constable; ***The Metamathematics of Programming Logics***; (MCS-8104018); $14,234; 12 mos.

A programming logic is a formal system in which programmers can specify computational problems, develop provably correct algorithms to solve them and then execute these algorithms. An implemented system provides mechanical assistance in all phases of this process. Theoretical work is needed to guide the design, implementation, and use of programming logics. Significant results have been obtained about programming logics. Future investigation will concentrate on the proof theory of an algorithmic theory of types, a theory which appears to be a necessary and perhaps sufficient programming logic.

Cornell University; Robert L. Constable and Alan J. Demers; ***On Logics for Program Development***; (MCS-8003349); $60,000; 12 mos. (Joint support with the Theoretical Computer Science Program & Software Engineering Program-Total Grant $173,705).

This research involves the judicious combination of the strong points of program development methodology and program verification in a logic for correct program development. This project will explore a logic of formal top down development, called a refinement logic. During the grant period a prototype system will be designed and built. This system will be used in extensive experimentation of the

refinement logic concept. Comparisons with other systems will also be conducted.

University of Texas-Austin: Robert S. Boyer and J. Strother Moore; ***Mechanizing the Mathematics of Computer Program Analysis***; (MCS-8116774 ; $93,368; 9 mos.

The present line of work has led to the development of an extensible formal theory for reasoning about the inductively constructed objects (e.g., integers and sequences) underlying the semantics of programs, and the development of an automatic theorem-prover for that theory. One measure of the success of the work to date is the list of difficult programs proved correct by the system: a simple optimizing expression-compiler, an expression-parser, a fast string-searching algorithm, a mechanical theorem-prover for propositional calculus, and an arithmetic simplifier. The deepest theorem proved thus far is the unique prime factorization theorem, which is derived entirely from the Peano axioms for integers and lists and previously proved theorems. Improvements to both the theory and the proof techniques will be pursued. These improvements will make it easier to state and prove many kinds of assertions (e.g., by providing recursive, schematic concepts), will ease the burden on the user during proofs (e.g., by mechanically inventing lemmas), and will increase the system's competence on many important domains (e.g., graphs, the rationals, combinatorics). The utility and feasibility of extending the system with subroutines proven sound by the system will be demonstrated.

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# Computer Systems Design

## VLSI Design Methodology

California Institute of Technology; Carver A. Mead; *Industry/University Cooperative Research: Design of Silicon Structures*; (MCS-7826367 A02); $61,437; 12 mos. (Joint support with the Electrical & Optical Computing Program, the Computer Engineering Program, and the Industry/University Cooperative Program-Total Grant $219,096).

The work of the Silicon Structure Project can be divided into two categories. The first category covers fundamental work directed towards increasing knowledge on subjects germane to integrated circuits design including: representation for design, modeling of physical phenomena in processing, verification of silicon, implementation of systems, development of design rules for stability and the generation of regular structures.

The second category covers the embodiment of this knowledge in computer programs to assist in the design process. These programs will use novel representations appropriate to different phases of the design to build design models that allow simplified checking and verification. They are directed towards producing workable compliers and debugging systems.

The Silicon Structure Project development of VLSI design tools is jointly sponsored by industry and NSF. The industrial sponsorship comes from a number of companies involved in manufacturing computers and semi-conductor components.

California Institute of Technology; Charles L. Seitz; *Second Caltech Conference on VLSI, January 1981*; (ECS-8025817); $4,500; 6 mos. (Joint support with the Theoretical Computer Science Program and the Computer Engineering Program-Total Grant $11,810).

This conference, similar in plan and emphasis to the 1979 Cal Tech Conference, features the research efforts underway both in industry and universities in VLSI architecture, design, and fabrication. The first day's session, involving invited speakers, is concerned with the possible restructuring of the microcircuit industry based upon the concept of the "silicon foundry" and implementation system. The concept of the "silicon foundry" was discussed in the 1979 conference proceedings. The second and third days are devoted to sessions on fabrication, innovative VLSI designs, computer-aided design, design principles, and computer architectures. Conference proceedings are to be published. The conference attendance is limited to approximately 600, and includes university, industry, and government attendees.

University of Illinois-Urbana; Saburo Muroga; *Logical Design Theory for Integrated Circuits*; (MCS-8108505); $96,488; 24 mos.

A major area in the study of logic design is that of minimization such as the minimization of chip area or device pin count in VLSI designs. This project focuses on such minimization and is exploring the following problems, some of which are extensions of previous research efforts by this group.

1. The development of procedures to design compact Programmable Logic Arrays and the variants and procedures to design compact arrays which are NAND networks in 3 or more levels is being pursued. The advantages and disadvantages of these procedures are being explored and compared.
2. The properties of minimal adders with different types of gates and minimal adders with extra functional capabilities (i.e., adders combined with logic operations) are being studied. Based on these properties, parallel multipliers are being designed and the properties of these multipliers explored.
3. Each technology being used for integrated circuit implementation has its own characteristics. Design methodologies must include consideration of these characteristics. The project will focus on minimal networks to be implemented using the MOS technology.

Cornell University; Edward D. Wolf; *National Research and Resource Facility for Submicron Structures*; (ECS-7709688 A04); $30,000; 15 mos. (Joint support with the Solid State & Microstructure Engineering Program, Division of Materials Research, and the Chemical Analysis Program-Total Grant $1,125,000).

The National Research and Resource Facility for Submicron Structures was established in July

1977. During its nearly three years of existence, the facility has made substantial progress, but it is still not mature. The operations of the facility were rapidly established in temporary laboratories in Phillips Hall. Equipment was ordered and installed, design and construction of a new building was initiated, core and visitor research projects were established and have produced excellent results, and duties of the information resource nature were discharged through the presentation of talks, research papers, the holding of open hourses, and the hosting of visitors and graduation of students trained in the area. In some areas, particularly in the quality and quantity of research results produced, the degree of support from the industrial community, and usefulness as an information resource, progress of the facilty has been faster than anticipated. In some other ways, the facility is now less mature than originally planned. Delays in delivery of some key items of equipment, delays caused by the necessity to relocate and redesign the new $3.4M laboratory being built by Cornell University, and a flaw in the original plan (foreseen and pointed out by many outside observers) which provided inadequate full-time support staff for the facility, have all contributed to the delay and curtailment of the facility's ability to fully serve users outside of the Cornell community. The supplemental funds allows the facility to meet its objectives by the end of the 5th year of this continuing grant through planned funding full time support staff.

Carnegie-Mellon University; Stephen W. Director and Daniel P. Siewiorek; ***Multi-Level Computer Aided Design of VLSI Digital Systems***; (ECS-7825755 A02); $88,200; 12 mos. (Joint support with the Electrical & Optical Computing Program and the Computer Engineering Program-Total Grant $176,400).

As the advances in integrated technology continue to be made with the realization of larger and more complex circuits on a single chip, it is imperative to consider the entire digital system-integrated circuit design as an overall procedure involving consistent design methodology and computer aids which are required to implement this design methodology. It is the purpose of this research program to develop a design procedure which in this phase includes multi-level synthesis and design, and methods of evaluation and evaluation metrics. Important research that is being considered involves a definition and evaluation methodology for the output design space, the independence of design parameters at one level on objective functions at another, the effect of a set of design parameters at different levels on the total object function, and the formulation of multi-level design optimization procedures and design space search strategies. Performance, cost, reliability, and testing are an integral part of the search for effective evaluation methodology.

The overall design and the consistent computer aids incorporate the flexibility that integrated circuit realizations provide while at the same time recognize the limitations imposed by the integrated circuit technology itself. Provision is being made to accommodate new technology advances.

Carnegie-Mellon University; H. T. Kung and Robert F. Sproull; ***Conference on VLSI Design: Theory and Practice at Carnegie-Mellon University September, 1981***; (MCS-8008165); $1,606; 12 mos. (Joint support with the Computer Engineering Program and the Theoretical Computer Science Program-Total Grant $4,818).

H. T. Kung and Robert Sproull will hold a two and one half day conference at Carnegie-Mellon University in September 1981. The conference will be focused on VLSI chip design. The presentations at the conference will include a half dozen invited talks and contributed papers. Both theoretical and practical aspects of chip design will be stressed.

University of Washington; Martin Tompa; ***VLSI Design Aids, and Inherent Complexity of Common Problems***; (MCS-8110089); $26,300; 24 mos. (Joint support with the Theoretical Computer Science Program-Total Grant $52,600).

The potential density of very large scale integrated (VLSI) circuits is increasing at a rate which is rapidly outpacing the ability of designers to exploit that density without the aid of sophisticated automated design systems. This project addresses two aspects of such systems; namely, the automated layout of circuit components and graphic tools for editing VLSI designs. In addition, the inherent complexity of several problems relating to VLSI circuits will be explored.

## Computer System Architecture

Illinois Institute of Technology; Anthony S. Wojcik; ***Design of Multiple-Valued Digital Systems***; (MCS-7901689 A01); $77,104; 24 mos.

Even though the use of multiple-valued logic offers several advantages over binary logic, the design of non-binary systems is considerably more difficult than the design of binary ones. Standard design procedures for multiple-valued systems are very restrictive. This research project approaches the design of such systems through the use of theorem proving programs. This approach is very flexible, allowing arbitrary sets of logic elements and the characteristics of the physical circuits to be used.

University of Illinois-Urbana; David J. Kuck and Duncan Lawrie; ***Computer System Organization***; (MCS-8001561 A01); $137,413; 12 mos.

This is a project aimed at moving forward the automation of computer system design on several levels. At the highest level, user Fortran programs are analyzed to obtain a rough idea of machine characteristics that are desirable for their efficient execution. The machines under consideration include those that execute single-array instructions, multiple-array instructions, and multiple-scalar instructions. Correspondences between program constructs and machine structures are measured by the analyzer. The analyzer may be thought of as a compiler prototype for these various machine structures. At the lowest level, the system can be used to accept behavioral descriptions of logic (e.g., sequential machine descriptions). The analyzer can take such a description, process it and map it into a structural description of the logic necessary to execute the behavioral description. As many technological constraints as possible will be incorporated to make this mapping realistic for VLSI circuit design.

University of Illinois-Urbana; James E. Robertson; ***Digital Computer Arithmetic***; (MCS-8109491); $91,340; 24 mos.

This project focuses on structures for arithmetic which are in some sense "universal." A theory of decomposituon of complex structures into a limited number of simple structures whose complexity is on the order of a binary half adder has been developed. The scope of the decomposition algebra is at present limited to structures involving addition and subtraction. The difficulty of design using the decomposition algebra appears to be linear with the number of input variables, whereas the difficulty of design for Boolean algebra grows exponentially with the number of input variables. The solutions resulting from the decomposition algebra give an indication of the internal connectivity of the simple basic structures. New developments of the theory of decomposition include:

1. It has been noted that mythical inputs can be used to simplify the design. For example, a full adder with one mythical input reduces to a specific form of a generalized half adder, since the mythical input is always zero. The task of identifying the effects of mythical inputs on all variants of the basic structures is being explored.
2. The conjecture that the one choice among many of the representations for a mythical input is that one choice which minimizes the information content is being explored.
3. The conditions under which the design of a combination of two or more structures as a single unit is simpler or faster than the combination of the component structures are being investigated.
4. A theory has been developed for the specialized case of normalized digit sets (zero offsets). A goal is to generalize this theory for non-zero values of offset and to explore ways of avoiding variants based on the superposition of an offset pattern.
5. The application of this approach to higher radix representations is being studied.

Massachusetts Institute of Technology; Jack B. Dennis; ***Data Flow Computer Architecture***; (MCS-7915255 A01); $81,891; 12 mos.

The Computation Structures Group is continuing its fundamental research on program structures and computer architecture for data flow computation. Areas being studied include: program transformations to better match program structure to a hypothetical data flow architecture; machine level program structure and code generation; hardware specification, verification and simulation based on an architecture description language for packet systems; and new methodologies for performance estimation and fault tolerance applicable to packet system architectures.

Northeastern University; Robert J. Lechner; ***Harmonic Analysis of Logic Functions I: Encoded Programmable Logic Arrays***;

(MCS-8108685); $15,864; 12 mos. (Joint support with the Theoretical Computer Science Program-Total Grant $31,728).

This research is concerned with the development and evaluation of a new unified approach to array logic synthesis using VLSI technology on a scale which applies to software storage as well as to firmware storage and wired control logic within digital systems. Specifically PLAs are imbedded within linear encoding transformations on their inputs and outputs and combined with ROMS as necessary to define more optimal implementations of logic functions or stored tables than are possible with either ROMS or simple PLAs alone. In contrast to more general array logic techniques, the imbedded PLA approach retains the homogeneous array device layout and interconnection topology that reduces design and testing costs.

Heuristic algorithms are developed and tested on realistic examples to evaluate the feasability of the imbedded PLA approach. Theoretical studies are used to evaluate a more rigorous approach to canonical synthesis algorithms that do not require human intervention. A crucial outcome of the study is the identification of that class of functions for which the hybrid (ROM + imbedded PLA) approach to synthesis is more cost-effective than either ROMS or PLAs alone.

University of Massachusetts; Harold S. Stone; *Control of Distributed Processes*; (MCS-7805295 A01); $73,802; 24 mos. (Joint support with the Computer Engineering Program-Total Grant $123,802).

Prior research has developed simple control algorithms based on commodity-flow graphs for controlling distributed computations. Attempts to extend the simple models in various ways have shown that the extensions are typically of the "hard problem" (NP-complete) class, for which no efficient algorithms for finding solutions in the worst case have been discovered. Recently results show that random graphs lead to notably simple optimal control strategies because of a strong clustering property. This project will investigate the statistical properties of distributed programs to determine if they exhibit the strong clustering property of random graphs. If so, near-optimal real-time control of distributed processes is achieveable in spite of the NP-complete nature of the problems on worst-case situations. The research is attempting to identify the statistical behavior of distributed computations through mathematical analysis and simulation. These results are being validated on a small testbed of a distributed system. If the results show a strong clustering property much like the working set phenomenon in virtual memory systems, then a practical algorithm can presume the form of a final solution immediately, and perturb the system slightly around this assumed form to find good near-optimal controlled states.

University of Michigan; Daniel E. Atkins; *High-Performance, Application-Directed Arithmetic Processors*; (MCS-8007298 A01); $82,236; 12 mos.

The objective of this research is to establish theory and methodology relevant to the synthesis and analysis of high-performance digital computers which are optimized for a given application. Such special-purpose or application-directed machines can provide very cost-effective solutions (in some cases, the only solution) to important computational problems (e.g., real-time, 3-dimensional image processing, weather prediction, numerical wind tunnels).

Since arithmetic is fundamental to high-speed computing, a major component of the project relates to the creation of a computer-based Arithmetic Design System (ADS). This tool is assisting in the quantitative analysis of alternate approaches to implementing arithmetic processors including use of many novel number systems other than the predominant "two's complement". Major components of the ADS include time-space complexity analysis, numerical analysis, formal verification, automatic exploration of structural alternatives, simulation, and interface to computer-aided logic design. The ADS is being applied to design studies in the context of very large scale integrated (VLSI) circuit technology.

The theory and methodolgy developed are being tested empirically by design and prototype construction of application-directed arithmetic processors.

University of Michigan; Trevor Mudge; *Sparse Linear Equation Solver*; (MCS-8009315); $149,013; 24 mos.

This project focuses research on the design and performance of an application-directed computer architecture for the high speed solution of large systems of sparse linear equations (LASSLEs). The importance of being able to rapidly solve LASSLEs can be inferred from the wide range of problems in which they occur. These include problems in the following: network analysis, finite element structural analysis, linear programming, electric power

system analysis, as well as the more recently developed field of image reconstruction. In all of these applications unrealistic problem simplifications are often necessary to reduce the LASSLE to proportions that are manageable for present-day computers. This research is aimed at making the high speed solution of LASSLEs practical by exploiting state-of-the-art hardware to tailor the architecture to the problem. An extension of the conventional SIMD architecture which will use some type of sorting network as a "gathering" mechanism to retrieve data from memory in a form that can be efficiently processed by an SIMD architecture is being investigated. The architecture will also use some type of sorting network as a "scattering" mechanism to return the processed results to memory. The investigation includes emulation of the architecture to enable its evaluation for LASSLE algorithms, and to compare its performance with competing architectures.

New York University; Jacob T. Schwartz; ***The VLSI Software Architectures Laboratory Oriented Toward Large-Scale Parallelism***; (MCS-7921258 A01); $160,500; 12 mos. (Joint support with the Computer Engineering Program-Total Grant $237,500).

This project addresses one of the most significant opportunities being opened up by the rapid development of LSI (Large-Scale Integration) technology, namely the possibility of organizing parallel computation on a very large scale (e.g. using thousands of processors) especially for purposes of scientific and artificial-intelligence related computation. This program of research on algorithms, hardware architectures, and programming style is underway.

State University of New York-Stony Brook; Richard B. Kieburtz and David R. Smith; ***Experiments in Distributed Computing***; (MCS-8102285); $36,934; 12 mos.

This research is experimentally evaluating some promising strategies for obtaining high performance from a network of small computers. Each node of the network is being employed in evaluating a small component of a large application. The parameters of these experiments include the granule size of individual computational tasks, the high-level protocols used by tasks which interact with one another, and strategies for problem decomposition, for scheduling of tasks and for storage management.

These experiments are being run on the Stony Brook Multicomputer, an experimental facility designed and built for this purpose. This facility has an embedded subsystem that can record a precisely timed history of designated events during an experimental run. From such a history, the important statistics of system performance are being extracted.

Specific experiments being performed include measurements of communication cost, relative to local processing; and evaluation of performance to determine optimum sizes of program modules to be executed at individual network nodes.

A secondary benefit expected from the research is the development and prototype testing of software required to support a hierarchically distributed computing systems. This represents the development of new technology which will be reported upon in the literature.

Southern Methodist University; David W. Matula; ***Foundation of Finite Precision Arithmetic***; (MCS-8012704 A01); $18,115; 12 mos. (Joint support with the Theoretical Computer Science Program-Total Grant $36,230).

Advances in LSI and VLSI capabilities are fostering an era where complex special purpose hardware for specific application areas will be realizable at acceptable costs. The ability to represent all sufficiently simple fractions and to evaluate reasonably small rational expressions exactly are important features making fixed-slash and floating-slash arithmetic interesting possibilities for special purpose architectures. Previous research has demonstrated that fixed and floating-slash systems are sufficiently competitive in arithmetic logic design requirements and representation and timing efficiencies to be serious candidates for special purpose architectures. The research is directed toward developing and assessing the viability of these arithmetic systems in the most promising areas of application: specifically, (i) assessment of the growth of accumulated error in fixed-slash and floating-slash computations; (ii) investigation of the suitability of these systems for incorporation in symbolic computation packages; (iii) for micro and small minicomputer systems-an assessment of the ability of a single firmware level fixed-slash (or floating-slash) arithmetic package to support moderate user level exact integer, exact rational, and approximate real computation capability; and (iv) investigation of enhancements of particularly extended range for floating-slash and algorithms for special purpose functions such as square root.

University of Utah; Robert M. Keller; ***Very General Purpose Multiprocessing***; (MCS-8106177); $87,245; 24 mos.

Integrated software/hardware concepts for multiprocessing systems within a primarily applicative framework are being considered. The advantages of such a framework include the ease with which computational tasks and their intercommunication can be set up, the ability to conduct program development by refinement without transcription to another language for implementation, and the naturalness with which programs can be represented in a machine. Questions being investigated concern system load balancing and processor and memory allocation, use of applicative languages as design tools, and the judicious incorporation of non-applicative features (such as resources management primitives) in languages with applicative bases. The significance of this work lies in its possible contribution to enhanced usability of multiprocessor computer systems, and greater facility in solving problems which can exploit such systems.

University of Washington; Jean-Loup Baer; ***Modelling and Evaluation of Parallel Processing***; (MCS-7609839 A02); $5,377; 6 mos.

This project is focusing on the modelling and performance evaluation of two parallel processing architectures. In the study of parallel processing, emphasis is on the modelling of control and data flow, performance measures, and the tailoring of algorithms and data structures to the parallel environment. In the area of memory management, the focus is on some "priori" restructuring of programs for the parallel processing environment and on policies for prepaging in this environment.

This supplement will support a graduate student during his doctoral thesis research effort.

University of Washington; Jean-Loupe Baer; ***Parallel and Distributed Processing***; (MCS-8025616); $65,416; 24 mos.

This research on parallel and distributed processing focuses on the following aspects:

1. The design of special-purpose multiprocessing units to enhance the computing efficiency of distributed-function architectures. A batched binary search unit and a directory or file server unit which processes searches and insertions are being explored.
2. The modeling and evaluation of distributed control algorithms. The modeling methodology uses colored Petri Nets. The emphasis is on protocols allowing failure recovery. The evaluation is mainly through simulation with the Petri Net models "flowcharting" the simulation program. Parameters in the simulation allow the comparison of the efficiency of various algorithms according to the structure of the communication link and the type of application.

University of Wisconsin-Madison; David J. Dewitt; ***Investigation of Data-Flow Machines for Relational Database Management Systems***; (MCS-7801721 A02); $15,183; 12 mos.

The database machine being considered is a specialized computer organization constructed with a large number of inexpensive processors. Such a computer is intended for efficiently processing database queries which access very large databases. A data-flow computer is a computer which uses the presence of data as the criterion for instruction initiation and control rather than the instruction's position in the program. While previous research has shown that the application of data-flow machine techniques to the processing of relational algebra database queries can significantly decrease their execution time, no architecture employing these techniques has been previously designed. This project will focus on the investigation of the properties of such a machine. In addition, alternative organizations for data-flow data base machines, multiprocessor algorithms for performing relational algebra operators, and mechanisms for both concurrency control and roll-back and recovery for data-flow database machines will be examined and evaluated.

University of Wisconsin-Madison; Leonard M. Uhr; ***Array/Network Architectures For Image Processing***; (MCS-8109103); $82,601; 24 mos.

Array/Network architectures are being designed and evaluated, with emphasis on:

1. finding hardware structures that fit well the data flow of the programs executed on them,
2. combining large array structures, which have been found extremely useful for image processing procedures at and close to the level of the very large raw input image, with suitably configured networks of more powerful processors.

This problem is being attacked as follows:

1. Network structures are being designed with these kinds of programs in mind, and examined for how well their local and global properties fit these programs requirements.
2. Graph Theory techniques are being used to help find good new architectures, new operations for generating new architectures, and good criteria for evaluation and comparing architectures.

## Fault Tolerance and Reliability

Stanford University; Edward J. McCluskey; ***Research on Reliable Computers***; (MCS-7904864 A02); $80,726; 12 mos.

Research aimed at developing a basic understanding of the techniques for designing reliable computers is the focus of this project. The major objective is to develop and describe systematic techniques for designing testability into digital networks and systems. The closely related problem of the interaction between the testability aspects of individual chips and modules, and system strategies for testing, rollback, and reconfiguration is also being investigated.

State University of New York-Binghamton; Mark Karpovsky and Stephen Y. Su; ***Detection Of Bridging And Stuck-Type Faults In Digital Networks***; (MCS-8021262); $114,028; 24 mos.

This project is exploring the problem of testing bridging (short circuit) failures in integrated circuits. Complete tests have been constructed for detecting bridging and stuck-at faults at the input and output pins of the standard computer components. This project will focus on the extension of these concepts to larger modular components. Specifically, research will focus on the following:

1. Generalization of results for testing bridging and stuck-at faults in basic standard digital components to the generation of complete test sets for detecting bridgings as well stuck-type faults in the input and output pins of ALU (arithmetic logic unit), PLA (programmable logic array), CPU (central processing unit), and some recent commercially available microprocessors;
2. Development of efficient algorithms for generating tests for detecting bridging faults inside the integrated circuit chips;
3. Finding the lower and upper bounds for the minimal number of tests for detecting all internal bridging and the mixture of bridging and stuck-at faults;
4. Generalization of the algorithms for testing both internal and external bridging and stuck-at faults in multiple-output networks; and
5. Exploring the efficiency in terms of computing time and memory space of the test generation algorithms developed.

## Computer System Performance Measurement and Evaluation

Stanford University; Donald L. Iglehart (In Collaboration With Gerald S. Shedler, San Jose Research Laboratory, IBM); ***Industry/University Cooperative Research: Discrete Event Methods For Computer System Simulation***; (MCS-7909139 A04); $78,749; 12 mos. (Joint support with Industry/University Cooperative Program-Total Grant $113,085).

This research is for the development of rigorous theoretical foundations for discrete event digital simulation. Primary motivation for the specific work is the need for firmly based methods applicable to simulations of computer and communication systems which, to a large extent, deal with congestion phenomena. Emphasis is on the development of new mathematical and statistical methods for queueing networks and stochastic point process models pertinent to the design of simulation experiments and the analysis of simulation output. Performance evaluation of computer and communication systems requires such methods.

University of California-Berkeley; Domenico Ferrari; ***The Dynamic Behavior of Computer Systems***; (MCS-8012900); $106,500; 24 mos.

This research project focuses on investigating the dynamic behavior of computer systems. Performance evaluation studies are usually concerned with steady-state behavior, i.e., with distributions of performance indices or distribution descriptors like means and variances. Time series of workload and performance variables are normally assumed to have stationary properties. However, transients are important whenever automatic mechanisms for performance control are involved. Closed-loop schemes already present for local optimal control in some operating systems are expected to become more important and more global in the next generations of systems. Knowledge of computer systems dynamics is needed for the design of much more complex operating systems, to keep system performance close to its optimum in spite of the workload's fluctua-

tions, and to avoid undesirable phenomena like instability.

An integrated approach based on empirical as well as modeling techniques is being explored. New evaluation techniques are being developed, and old ones, are being adapted. The ultimate goal is the construction of a simple performance controller and the evaluation of its effectiveness.

Washington University; Mark Franklin; ***Continuous Systems Simulation on Multiprocessor Systems***; (MCS-7820731 A02); 40,000; 12 mos. (Joint support with the Special Projects Program-Total Grant $117,148).

The principal goal of this project is to increase significantly the solution speed and reduce the costs associated with continous system simulation on computers. The principal vehicle for achieving this goal is the exploitation of multiple processor computer architecture, in particuarl architecture based on Very-Large-Scale-Integration Technology (VLSI).

The research will be conducted in there main areas:

1. Algorithms, parallel integration methods and higher order numerical problems associated with simulation.
2. Systems architecture, quantifying hardware and software design parameters and system performance metrics.
3. Systems building and research tools development, development of a systems workbench on which new ideas of structure and algorithms can be tried.

Carnegie Mellon University; Peter Hibbard and Neil S. Ostlund; ***Performance Evaluation of Multiprocessor Computer Systems***; (MCS-7920698 A01); $66,681; 12 mos.

This project focuses on a multifaceted exploration of the performance characteristics of a fully operational multiprocessor computer system, Cm*. This computer has 50 DEC LSI-11 processors with the potential for expansion up to several thousands of processors, and a novel microprocessor-controlled hierarchical switching structure for accessing memory.

While there has been a reasonable amount of theoretical work on parallel algorithms, very little practical evaluation of applications on asynchronous multiprocessors has been performed. This is primarily due to the small number of operational systems which have a substantial number of processors and the requisite general-purpose software. Cm* provides a unique research opportunity for investigating the actual performance benefits available from multiprocessors when they are applied to important computational problems.

The specific areas of research include implementation of some standard relatively simple, benchmark systems on Cm* including partial differential equations, integer programming and matrix operations, implementation of some algorithms used for real-time graphics displays, investigation and possible implementation of an Integrated Circuit design validation system, and the development and implementation of algorithms for the major steps in molecular orbital calculations in quantum chemistry which are quite complex, and employ many numerical techniques common to other large computational problems. Successful demonstrations of this application on Cm* would be major evidence of the effectiveness of the Cm* architecture for a wide range of scientific calculations.

University of Texas-Austin; K. Mani Chandy; ***Algorithms for Computer Performance Analysis***; (MCS-8101911); $72,635; 24 mos.

This project focuses on the development of algorithms and computer programs for predicting the performance of distributed and highly parallel computing systems. Algorithms to model systems with very large populations and large numbers of classes, multi-processors, priority scheduling, multi-tasking, and using a variety of communication protocols will be explored.

University of Washington; John Zahorjan; ***The Approximate Solution of Large Queueing Network Models***; (MCS-8104879); $50,692; 24 mos.

This project focuses on the approximate solution of large gqeueing network models as used in computer system performance evaluation and prediction studies, models for which known exact solution techniques require prohibitive time and memory resources. Such models may arise either in cases of large computer systems, such as decentralized systems, where even product form solution techniques are computationally infeasible, or in cases where aspects of the computer system important to its performance characteristics require models of a very general class (global balance models), whose solution is inherently expensive.

A fundamental requirement of a number of recent approximation techniques, the solution of general, two-queue networks will be addressed. The aim of this research is to extend queueing network modeling technology so that larger and more detailed models can be used as practical tools in system modeling.

## Computer Graphics

Stanford University; Joseph W. Goodman and Albert Macovski (in collaboration with J. Pearson, Lockheed Palo Alto Research Laboratory); *Industry/University Cooperative Research: Multiplexed Holographic Reconstruction Methods for Three-Dimensional Structures*; (ECS-7926432 A01); $23,139; 12 mos. (Joint support with the Automation, Bioengineering & Sensory Systems Program and the Industry/University Cooperative Program-Total Grant $173,128).

The research addresses the problem of displaying data so that special relationships can be visualized. The research rests on certain recent theoretical developments in the field of computerized tomographic imaging. Methods appropriate to the problem of three-dimensional visualization are being investigated which lead to computer software concepts suitable for implementing in computer algorithms. A particular concept of reprojection is being explored which can be realized in a multiple hologram giving a three-dimensional image. The possible utility of such displays for visualizing spatial relationships is being tested on both data derived from nondestructive testing of metal structures and data derived from medical diagnostic testing.

Harvard University; Peter J. Huber; *Interactive Graphical Analysis of Multidimensional Data*; (MCS-7908685 A02); $6,500; 12 mos. (Joint support with the Statistics & Probability Program-Total Grant $26,000).

Professor Huber will work on the development of computer methods for statistical data analysis. The goal is to combine the superior data handling facilities of computers with the superior pattern discovery ability of humans. Emphasis will be placed on analysis of multidimensional data, techniques for reduction of dimensionality and minimization of functions.

State University of New York-Stony Brook; Zvi M. Kedem; *Stochastic Modeling of Complex Phenomena in Computer Graphics*; (MCS-8110097); $71,978; 24 mos.

The investigation of stochastic techniques for modeling complex natural phenomena is being continued under the auspices of this grant. The most promising avenues for this research appear to involve the extension of the stochastic terrain models developed under NSF Grant MCS-7901168. Such extensions are being pursued in order to generate realistic models of three-dimensional objects and of the motion of complex objects. Both evolutional and parallel decompositions for modeling motion by appropriate four-dimensional stochastic processes (possibly partially degenerated into deterministic processes) is being investigated. The search for efficient algorithms for rendering newly-developed models whose properties are well-suited to computer graphics environment is an integral part of this research. It is anticipated that the research will lead to algorithms for more realistic modeling of phenomena such as trees, clouds, terrains, Brownian motion of molecules, ocean waves, etc., considerably widening the scope of computerized modeling for graphic display. This is a cooperative project with Donald Fussell at the University of Texas-Austin.

Ohio State University; Franklin Crow; *Toward More Complicated Computer Imagery*; (MCS-7920977 A01); $43,978; 12 mos.

The realism and utility of computer generated shaded images is severely limited by the meager complexity of the scenes which can currently be handled. In an attempt to improve on this situation, a conventional scan-order hidden surface and display algorithm was extensively modified to enable images of 100 times greater complexity. Experience with these more complex images has reinforced the understanding of how much more complicated truly satisfactory images will have to be.

Hidden-surface algorithms currently in use are limited by sorting steps which require the presence of all data. The data describing scenes are defined inflexibly, making distant views computationally inefficent and closeups lacking in detail. In addition, the production of truly complicated images will require distributing the algorithms over many processors in order to make animated imagery cost effective. These highly interrelated problems are being explored by studying and implementing algorithms designed for concurrent processing environments and oriented to more intelligently defined shape descriptions.

Initial efforts will focus on the design of data structures to support efficient rendition of the same object at many different levels of detail. Subsequent work will focus on algorithms for the display of such objects which are designed for distributed execution. Finally, the algorithms will be implemented and image sequences produced on a multicomputer facility currently being acquired.

Ohio State University; Charles A. Csuri, Richard E. Parent, and Karl Olson; ***Complex Animation and Complex Object Synthesis***; (MCS-7923670 A01); $139,913; 12 mos.

This research concentrates on four tasks dealing with complex motion systems and complex object synthesis. The four research tasks are: complex motion specification and control, surface generation based upon skeleton representation, three-dimensional texture, and points as a graphics primitive.

New algorithms are being developed to mathematically model complex motion systems. As a case study human motion has been selected because it involves parallel processes and it has great dynamic complexity and nonlinearity. Special purpose hardware will be designed and constructed to test these algorithms for real-time display.

An interactive surface generation system is being implemented to create three-dimensional structures from skelton representations.

Algorithms are being developed to simulate visual cues for 3-D surface detail. An attempt will be made to use a portion of the DMAAC (Defense Mapping Agency) data base.

An investigation is being made of points as a graphics primitive. An analysis is being made of the data structure and animation requirements for use in displaying visual results from scientific models.

University of Texas-Austin; Donald Fussell; ***Stochastic Modeling of Complex Phenomena in Computer Graphics***; (MCS-8109489); $59,861; 24 mos.

The investigation of stochastic techniques for modeling complex natural phenomena is being continued under the auspices of this grant. The most promising avenues for this research appear to involve the extension of the stochastic terrain models developed under NSF Grant MCS-7901168. Such extensions are being pursued in order to generate realistic models of three-dimensional objects and of the motion of complex objects. Both evolutional and parallel decompositions for modeling volumes are being considered. The feasibility of modeling motion by appropriate four-dimensional stochastic processes (possibly partially degenerated into deterministic processes) is being investigated. The search for efficient algorithms for rendering newly-developed models whose properties are well-suited to computer graphics environment is an integral part of this research. It is anticipated that the research will lead to algorithms for more realistic modeling of phenomena such as trees, clouds, terrains, Brownian motion of molecules, ocean waves, etc., considerably widening the scope of computerized modeling for graphic display. This is a cooperative project with Zvi Kedem at State University of New York-Stony Brook.

University of Utah; Robert E. Barnhill; ***Computer Aided Surface Respresentation And Design***; (MCS-8101854); $135,416; 24 mos.

The goals of this research are to develop new methods of representing and designing free form surfaces in an interactive computer graphics setting. This involves the following steps:

1. the invention of new surface approximations;
2. making these approximations into algorithms suitable for interactive graphics displays;
3. writing the necessary computer code; and
4. testing the algorithm, including the finding of suitable test examples.

In addition, criteria for the selection of the "best" algorithms for given purposes will be explored.

# Software Engineering

## Quality Software

Stanford University; George B. Dantzig, Richard W. Cottle, and Walter Murray; ***Computer Optimization of Complex Systems***; (MCS-7926009 A01); $115,375; 12 mos.

The Systems Optimization Laboratory (SOL), Department of Operations Research, Stanford University, is a center for research in mathematical programming and its applications. Research activities include both algorithmic development and model development with interaction between them, so as to reduce the gap which normally separates these two areas in practice. The topics of research include:

1. Efficient methods for large-scale "staircase" and other specially structured linear programs. Of particular interest are the continuous simplex approach, methods based on decomposition, and factorizations designed for staircase matrices.
2. Several refinements and extensions to the MINOS code for large-scale linearly constrained optimization.
3. Analysis of several topics in nonlinearly constrained optimization.
4. A study of Newton-type, sparse quasi Newton, and conjugate gradient methods for large, sparse, unconstrained optimization. It is anticipated that the results in the unconstrained case should suggest useful approaches to the large sub-problems that arise in constrained optimization.
5. Methods for large, sparse linear least squares, structured quadratic programs, and constrained linear and nonlinear least squares.
6. Evaluation and comparison of algorithms for various classes of optimization problems.

This work will also include an effort to collect sets of test problems that are non-trivial and representative.

University of California-Los Angeles; Thomas Liggett; ***Statistics and Infinite Particle Systems***; (MCS-8002732 A02); $13,700; 12 mos. (Joint support with the Statistics & Probability Program-Total Grant $85,517).

Stone will investigate the asymtotic properties of procedures for nonparametric regression and classification and parametric model selection. Ferguson will work on computational aspects of Bayes decision rules with respect to priors which are mixtures of Dirichlet priors in certain nonparametric problems. Ylvisaker will work on interval estimates for the parameters of approximately linear models and the adaptation of these estimates to real data. Jennrich will study derivative free statistical algorithms and their application to covariance structure analysis. Liggett will work to develop and apply new monotonicity properties of spin systems, and will study new processes on noncompact spaces. Durrett will study the asymptotic distribution in time, stability of stationary distributions under small perturbations, and phase transitions for certain processes.

University of Colorado at Boulder; Leon Osterweil and Lloyd D. Fosdick; ***TOOLPACK: University Of Colorado Participation***; (MCS-8000017 A01); $104,735; 12 mos.

TOOLPACK is a systematized collection of software tools to facilitate the development and maintenance of FORTRAN programs. The collection will be a mechanism to promote the use of high quality tools in software engineering research and in the development of numerical software. The project is a collaborative effort between universities, government and industry. The cooperating organizations are Argonne National Laboratories, Bell Laboratories, International Mathematical and Statistical Libraries, Inc. (IMSL), Jet Propulsion Laboratory, Numerical Algorithms Group (NAG), Purdue University, University of California, Santa Barbara and the University of Colorado.

Yale University; John A. Hartigan; ***Clustering Algorithms***; (MCS-8102280); $37,706; 12 mos. (Joint support with the Statistics & Probability Program-Total Grant $62,706).

The goal of this project is the development, validation, coding and distribution of clustering algorithms.

Statistical properties of standard algorithms will be studied to prepare a basis for their evaluation and modification. Asymptotic behavior of the k-means technique has suggested a test for the presence of two or more clusters, and its behavior for

many clusters in many dimensions will be studied. A theory of high density clustering suggests that single linkage is superior to the standard hierarchical techniques in detecting high density regions (or modes) in the data, but also that single linkage might be improved. Likelihood ratio tests for modes of densities carried by the minimum spanning tree (using maximum likelihood techniques for parameters constrained to lie in a partial order) suggest that improved clusters may be obtained by smoothing the minimum spanning tree adaptively. The asymptotic theory, empirical distributions of test statistics, and practical coding of minimum spanning tree smoothers will be undertaken. Work will continue on developing a statistical theory for block clustering, and for developing algorithms to construct block clusters from non-standard data structures.

Purdue University; John R. Rice; ***Template Processors and TOOLPACK Evaluation***; (MCS-7926310 A01); $43,555; 12 mos.

TOOLPACK is a systematized collection of software tools to facilitate the development and maintenance of FORTRAN programs. The collection will be a mechanism to promote the use of high quality tools in software engineering research and in the development of numerical software. The project is a collaborative effort between universities, government and industry. The cooperating organizations are Argonne National Laboratories, Bell Laboratories, International Mathematical and Statistical Libraries, Inc. (IMSL), Jet Propulsion Laboratory, Numerical Algorithms Group (NAG), Purdue University, University of California, Santa Barbara and the University of Colorado.

University of Maryland; James M. Stewart and Robert J. Munn; ***The Development of a Generalized Transportable Software Package for the Solution and Refinement of Molecular Structures by Single Crystal Diffraction Techniques***; (CHE-7920201 A01); $19,000; 12 mos. (Joint support with the Structural Chemistry and Thermodynamics Program-Total Grant $57,964).

Professors J. M. Stewart and R. L. Munn plan to develop a highly integrated system of generalized computer programs for the analysis of single crystal diffraction data. The developed programs will serve scientists interested in applying single crystal analysis to varied problems in chemistry, geology, biochemistry, mineralory, material science, and related disciplines.

The project will utilize a portable preprocessor in the implementation of the library of programs. The programs developed will be highly transportable, well documented, and optimizable at the user's site. They will be designed to work on "midi" through "maxi" computers either in a batch or, where appropriate, interactive mode.

The crystallographic programs will be designed to treat all types of compounds from simple mineral substances to very high molecular weight compounds such as proteins. They will be general with respect to space group and setting. In addition, the system will form and maintain a data base for each problem under study. Multiple algorithms will be implemented for basic operations where appropriate.

Massachusetts Institute of Technology; Virginia Klema; ***Experimental Computing in Numerical and Statistical Analysis***; (MCS-8006936); $165,076; 24 mos.

The research that will be conducted includes the design of models for the behavior of mathematical software for nonlinear optimization. Along with the models for the behavior of software for nonlinear optimization it will include the selection of start for the optimization problem and introduction of scale in the parameters of the problem. Research on the design and implementation of a symbolic function to be optimized will be started. The scanning of the function can determine the degree of nonlinearity of the function, the number of linear and nonlinear parameters in the function, the analytic derivatives that may be required, selection of the most appropriate optimizer, and the software interface to the selected optimizer. The emphasis throughout this research will be focussed on reliable mathematical software for a wide variety of computing machines.

## Symbolic and Algebraic Manipulation

University of Illinois-Chicago Circle; Vera Pless; *Computer Algorithms in Finite Groups and Combinatorial Structures*; (MCS-7924986 A01); $8,000; 12 mos. (Joint support with the Algebra and Number Theory Program-Total Grant $26,882).

This is a continuation of work done previously under MCS-7717272 A01 and is in the areas of combinatorics, computer algorithms, investigations of group theoretic and combinatorial objects on a computer, error-correcting codes, and development of a computer system.

In the area of error-correcting codes, Leon and Pless will complete their investigations of ternary self-dual (24,12) codes. They will compute the mass of the (40,20,8) doubly-even codes -and if the number is reasonable, classify them. Pless will investigate the possible primes which can divide the order of either a doubly-even (72,36,16) or a quaternary (24,12,10) in order to either contruct these codes or eliminate these primes.

Leon will develop and implement algorithms for computing automorphism groups and determining equivalence of block designs and graphs. He will also improve the Schreler-Todd-Coxeter-Sims algorithm for determining the order of permutation group with degree between 100 and 10,000.

Leon and Pless will continue to improve their computer system CAMAC. They are completing a manual and will improve the index, conjugacy class, and relations programs. They are attempting to make CAMAC more accessible to potential users. In addition, they are developing a PL-1 CAMAC which has dynamic storage allocation, structured programs, interruptible command and an editing facility. Much of the research described above uses CAMAC and provides motivation for the types of programs devoloped for the system. The algorithms developed will be implemented in CAMAC.

University of New Mexico; Stanly Steinberg; *Symbolic Methods in Partial Differential Equations*; (MCS-8102683); $19,972; 24 mos. (Joint support with the Applied Mathematics Program-Total Grant $39,944).

This project involves the development of symbol manipulation programs that will operate in MACSYMA for solving partial differential equations using symmetry methods. If the attention is focused on one parameter transformation group of symmetries, then the group will have an infinitesimal generator which is determined by a system of linear differential equations. When the system is solved symbolically, the resulting expression becomes exceedingly large. By the use of MACSYMA the limitation can be mitigated.

University of Wisconsin-Madison; George E. Collins; *Algebraic Algorithms and Systems*; (MCS-8009357 & A01); $124,017; 24 mos.

This project involves the study of five related research areas in symbolic and algebraic manipulation. These topics are:

1. polynomial factorization,
2. cylindrical algebraic decomposition,
3. polynomial residue class rings,
4. linear diophantine equations, and
5. development of the SAC-2 symbolic manipulation system.

## Software Studies & Metrics

University of Connecticut; Edward Balkovich; *The Performance of Decentralized Software*; (MCS-8007466 A01); $33,469; 12 mos.

Many of the objectives used to justify distributed computing can only be achieved by decentralizing both hardware and software. Decentralized software requires interacting, concurrent processes. Their implementation can be costly; however, decentralized software frequently exhibits better performance characteristics than its centralized counterpart due to parallelism. The objectives of this investigation are: (1) to measure the implementation costs for decentralized software using a distributed computer system, and (2) to develop and validate models that explain the performance of decentralized software in terms of implementation costs and software structure. The technical approach will use an existing experimental programming language and distributed computer system to obtain performance measurements for use with probabilistic performance models. The results will help to establish the costs of decentralizing software and the costs of

distributing computing. They will also serve to extend existing software engineering methods to include quantitative techniques that are suitable for comparing alternative, concurrent software designs.

University of Connecticut; Taylor L. Booth; ***Design of Optimized Computational Systems Using Probabilistic Performance Modelling Techniques***; (MCS-7903955 A01); $98,004; 24 mos.

A computer aided design system is being developed to aid an experienced software engineer in carrying out the performance analysis activities necessary to ensure that a system satisfies its performance requirements. A set of prototype design tools have been developed. The next step is to use these results to develop an integrated performance design support system. This system will use a symbol manipulation support system to carry out the complex algebraic steps found in many performance analysis studies, and an instrumentation and measurement system to study the properties and behavior of specific software systems under normal operating conditions.

The current research has dealt mainly with the modeling of sequential calculations. This work will be extended to include modeling and analysis techniques for concurrent, distributed and time varying systems. Results of this work will be used to develop additional tools to support the design of a larger class of software systems.

Iowa State University; Dennis G. Kafura; ***A Comprehensive Study of Software Metrics for Large-Scale Systems***; (MCS-7902970 A02); $79,527; 24 mos.

Recent research has established a set of metrics which are particularly appropriate for large-scale systems. These metrics are based on two principles: (1) the connectivity of the system is the primary determinant of system structure, and (2) the information flow among components is the single best method to define the connectivity. Metrics based on this information flow concept are capable of determining "missing levels of abstraction", "stress points, "module complexity" and other important system properties. This research involves a series of extensions to the information flow metrics which build upon the basic research already completed. Four specific objectives are established which involve enhancements to the existing metrics, the development of measurement tools, comparison with other metrics and extensive validation experiments.

This is a joint project with Dr. Sallie Henry of the University of Wisconsin-La Crosse.

University of Maryland-College Park; Mark Weiser; ***Investigation of Programming Aids and Program Metrics Based on Program Slices***; (MCS-8018294); $65,459; 24 mos.

This research will explore a new theory which can automatically relate data abstractions to program structures in existing programs. This theory is called "program slicing". This research builds on already completed mathematical work on the basis of slicing, and psychological experimentation indicating its practical value. New research will concentrate on two specific uses of slicing theory: (1) as a source of program metrics, and (2) as a program debugging and maintenance tool. These uses will be evaluated by trials on pre-existing programs, by psychological experimentation, and by actual use in programming projects. It is believed that the results of this research will contribute to understanding the human factors of programming, as well as practical programming aids.

Massachusetts Institute of Technology; Roy Kaplow; ***New Interactive Computer-Use Strategies Based on the Enhanced-Input Terminal System***; (MCS-7804755 A02); $45,000; 12 mos. (Joint support with the Special Projects Program-Total Grant $90,000).

A new type of computer terminal has been developed with enhanced capabilities for user input, including: user-defined, potentially unlimited symbol set; user-defined, free-format, touch-activated keyboards; and dynamically changing, software and user-controlled keyboard presentations which follow task progression. The terminal is based on graphical display device on which any keyboard design can be displayed instantaneously. This project will extend and examine the reach of this new environment for computer interaction through a two-faceted project. First, it will establish broad, affordable and more varied access through distribution over an existing two-way cable-TV network, and second, it will explore the impact of this new user/computer/video interface through study of usage patterns and through research on new languages and language concepts which the system makes feasible.

Such interfaces may have significant impact on the use of computers by non-experts, and by persons with mental or physical disabilities.

University of Wisconsin-La Crosse; Sallie M. Henry; ***A Comprehensive Study of Software Metrics for Large-Scale Systems***; (MCS-8117742); $42,000; 24 mos.

Recent research has established a set of metrics which are particularly appropriate for large-scale systems. These metrics are based on two principles:

(I) the connectivity of the system is the primary determinant of system structure, and (2) the information flow among components is the single best method to define the connectivity. Metrics based on this information flow concept are capable of determing "missing Levels of abstraction", "stress points", "module complexity" and other important system properties. This research involves a series of extensions to the information flow metrics which build upon the basic researach already completed. Four specific objectives are established which involve enhancements to the existing metrics, the development of measurement tools, comparison with other metrics and extensive validation experiments.

This is a joint project with Dr. Dennis G. Kafura of the Iowa State University.

## Program Testing & Verification

Tulane University; Johnette Hassell; ***The Development and Evaluation of Computer Program Testing Methods***; (MCS-8103617); $25,048; 24 mos.

The goal of this project is to enhance the theory and practice of computer program testing. Both theoretical research and experimentation will be used to study methods of testing as well as metrics which are useful in the testing process. The method of domain testing is to be extended and algorithms for the selection of test points improved. A new testing method, logic-driven bouondary testing, will be explored. Questions concerning its implementation are to be answered, and its efficiency and practicality are to be determined. Metrics which will provide measurements that will aid in choosing testing methods and in evaluating how well a testing method performs will be developed. This research is intended to contribute to improvements in the quality of computer software.

University of Massachusetts-Amherst Campus; Lori A. Clarke; ***A Partition Analysis Method to Demonstrate Program Reliability***; (MCS-8104202); $38,992; 12 mos.

Program testing and program verification have long been considered unallied, competing approaches to demonstrating program reliability. Neither approach is infallible, yet they complement one another nicely. The partition analysis method integrates testing and verification in an attempt to counterbalance the weaknesses of each approach by the strength of the other. By analyzing the implementation and the specification of the problem, the method partitions the problem domain into procedure subdomains so that all elements of each subdomain are treated uniformly by the specification and processed uniformly by the implementation. The procedure subdomains provide the basis for the application of both verification and testing techniques.

This research includes the application of partition analysis to an extensive class of problems, the development of improvements to the methods, and studies of its effectiveness for demonstrating program reliability.

Ohio State University; Stuart H. Zweben and Lee J. White; ***An Approach to Program Testing Based on Modularity***; (MCS-8018769); $110,000; 24 mos.

This project will investigate the extent to which testing of large computer programs can be facilitated by modularity in their development. Assuming that subunits (modules) of the total program are developed and tested independently, it would be desirable to make use of the information obtained in these unit tests when performing the validation of the large program. If this can be done successfully, there would be a significant reduction, as compared with conventional methods of testing, in the total amount of testing that would be required.

The approaches suggested involves varying not only the amount of test data required but the method of selecting this data. They also involve consideration of the degree of testedness of the individual units being integrated. Finally, some aspects of the research lend themselves to consideration of the particular methodology used to develop the resulting programs. It is therefore expected that a greater understanding of the relationship between software validation and other phases of the software lifecycle will result from this investigation.

## Software Tools and Programming Environments

University of Arizona; Christopher W. Fraser; ***Generalizing Command Languages and Utilities***; (MCS-8102298); $59,906; 24 mos.

Command languages and the utilities they invoke are among the most visible components of a computer system. Unfortunately, they are often unnecessarily inconsistent and restrictive. For example, some software systems provide utilities that can delete all files with a given attribute, but conversely cannot delete all files not having that attribute. The capability is there,but there is no way to invoke it.

This research attacks these problems with a new organization for common utilities and a new command language for invoking them. A simple, concise language will make it easy for users to assemble their own utilities from a library of tools when existing utilities cannot meet such a need. Such a software system should be smaller, faster, more flexible, and easier to learn than its more conventional counterparts. Coincidentally, it should regularize currently ad hoc text processors. Experiments will be run to test these hypotheses.

University of Arizona; Ralph E. Griswold; ***High-Level Programming Language Facilities For Data Structure Processing***; (MCS-8101916); $55,155; 12 mos.

This project involves the investigation of high-level programming language facilities for processing strings and structures.

Previous work has concentrated on two efforts: (1) the design of new facilities for characterizing and processing nonnumerical data, and (2) the implementation of these facilities so that they can be evaluated and made available to the computing community. There is a close interaction between these two efforts: the value of new facilities often can be determined only by their application to real problems. Conversely, the use of new facilities frequently suggests new possibilitites and neglected areas of application.

This research will build on past results and focus on three areas of investigation: (l) goal-directed expression evaluation and control structures that are needed for processing complex data structures, (2) high-level string processing facilities,including extension of present concepts of pattern matching and the development of paradigms and tools for implementing pattern matching, and (3) generalization of these concepts to high-level list scanning and pattern-matching facilities.

University of California-Irvine; Peter A. Freeman; ***Software Construction Using Components***; (MCS-8103718); $48,839; 12 mos. ( Joint support with the Air Force Office of Scientific Research-Total Grant $97,678).

This research involves the effective use of software components. Previous research has resulted in a running prototype system (Draco) which permits the rapid production (with minimum human interaction) of moderate sized programs (1000 lines of executable code) from preexisting software components. Draco is based on the concept of domains that model sets of objects and operations and refinements to reduce expressions in a domain into executable code. The Draco technology employs source-to-source transformations (in each domain) to provide effective optimization of the code. Executable code is produced by refinements into lower-level domains. The overall objective of this project is to push the Draco technology as far as possible to determine its strong and weak points. The specific objective is a demonstration of Draco's capabilities by building three different applications systems of approximately 10,000 lines of code each in a total time of 6 weeks.

University of Southern California; Robert M. Balzer and David Wile; ***Supervisory Control of Transformational Implementation Systems***; (MCS-7918792 A01); $109,125; 12 mos. (Joint support with the Software Systems Science Program-Total Grant $218,250).

This project is aimed at the long-term development of Transformational Implementation Systems. The work falls into two categories, systems building and fundamental research. The systems building activity provides essential support as a means of building an experience base for developing the insights and perceptions which guide the research and as an experimental vehicle for testing ideas and hypotheses.

The ultimate system is presently seen as having five sets of facilities:

1. facilities to impose a structure on transformation selection and application, involving plan-

ning subsystems, documentation subsystems and maintenance subsystems.

2. facilities to prove applicability criteria of properties of transformations. Transformations may be applied before some properties are proved applicable necessitating subsequent proof of such properties by inference or symbolic execution or via a general purpose theorem prover or a special purpose property prover.
3. facilities to do automatic program simplification and to provide automatic application of low level transformations that seek canonical forms.
4. facilities for combining individual transformations into layer coordinated packages.
5. facilities to generate new transformations for the catalog on the basis of interactive user editing of the state of the program being generated.

University of Colorado at Boulder; William M. Waite; *Code Generation Tools and Techniques*; (MCS-8108063); $55,350; 12 mos.

The goal of the project is to continue the implementation and evaluation of an integrated set of code generator construction tools. The primary emphasis will be upon reduction to practice: Demonstration that certain techniques can be applied routinely by compiler writers to produce viable code generators at acceptable cost. Since automatic code generator construction is feasible at this time, a skilled human must still make appropriate tradeoffs in describing the relationships between source and target concepts. The intent of this effort is to aid in identifying the decisions that must be made and to automate many of the routine tasks that must be subsequently carried out.

Purdue University; Walter F. Tichy; *Research on Configuration Management for Programmed Systems*; (MCS-8109513); $40,754; 24 mos.

Configuration management is the discipline of rigorously controlling the evolution of complex systems. Its goal is to ensure an orderly, structured, and traceable development process. Although configuration management for physical systems is well established, its techniques are essentially unsuitable for software systems. This research focuses on advancing the state of the art in software configuration management with the goal of improving both software quality and software production methods.

Specifically, research in the following two areas will be conducted:

1. Foundations of software configuration management. The project will build a conceptual basis for software configuration management. It will develop the fundamental notions and algorithms suitable for identifying, controlling, and tracking configurations of software and hardware/software system families. A general model for multi-version, multi-configuration programmed systems has been developed and will be used as a starting point.
2. Experimentation with software configuration management. A prototype support environment that automates essential functions of configuration management will be constructed. Various control procedures will be implemented and assessed experimentally. The goal is to build a convincing case that the conceptual basis meets the need.

Massachusetts Institution of Technology; Gerald J. Sussman and Carl E. Hewitt; *Computer Aided Evolutionary Design for Software Engineering*; (MCS-7912179 A01); $55,000; 12 mos. (Joint support with the Intelligent Systems Program-Total Grant $110,000).

Large software systems are generally associated with high cost and low reliability. These problems are not due primarily to sloppy programming or poor management, but rather are symptoms of the lack of technology for aiding software engineers in the process of evolutionary design. The fundamental issues involved in constructing an interactive computer aided design tool for software engineering will be investigated. The principles developed in this research should be applicable to the construction of similar aids for other engineering disciplines. Automatic program verification techniques now available form only part of the methodology necessary to provide powerful assistance to the designers and implementers of large systems. Verfication techniques are most suitable for proving the correctness of algorithms. The complexity and evolutionary nature of software systems requires a number of additional techniques.

The evolutionary nature of large systems is partiallly due to the fact that simplifying assumptions must be made in order to come up with an initially feasible design. Unfortunately, such "first order" designs need to be debugged when the simplifying assumptions are relaxed. This calls for design aid techniques which deal effectively with changing and incomplete specifications.

The managing of complexity is a fundamental issue in all engineering disciplines. Identified are three major techniques used in more mature engineering fields such as electrical and mechanical engineering which seem applicable to the engineering of software systems, incremental modelling, multiple and almost hierachical decompostion, and analysis by inspection.

University of Minnesota; G. Michael Schneider; ***An Experimental Investigation of Novice/Expert Behavior in Program Comprehension***; (MCS-8016549 A01); $26,263; 12 mos.

This research project will investigate the cognitive processes that come into play during an attempt to read and understand a program listing. Verbal protocols will be collected from a number of different subjects, and scored and analyzed in order to categorize the strategies and mental operations which are taking place. The questions to be answered are:

1. How is information extracted from the semantic/syntactic construct of a program?
2. How are hypothesis about program behavior proposed and confirmed, and in what order?
3. Are the approaches of novices/experts significantly different? If so, in what way? and
4. Can we propose a general model of the program comprehension process.

University of Nebraska-Lincoln; David W. Embley; ***A Forms-Based Nonprocedural Programming System***; (MCS-8105563); $50,628; 24 mos.

The extent to which ordinary forms can be exploited to provide a basis for a nonprocedural programming system will be investigated. In applications where forms are common, it appears that a system where an application programmer specifies computing processes, directs information flow, and formats data by sketching forms has promise of success. In previous work, the notion of a form has been rigorously defined, and a dual relationship between forms and programming languages and between forms and an appropriate database model has been established. This dual relationship provides a sound basis for a forms-based programming language and a forms-based query language.

Further investigation requires the implementation of a prototype system so that questions about system resource limitations and human interface capacities can be assessed. It is expected that this project will yield insight to the question of whether an application specialist who is a nonprogrammer in the traditional sense but is thoroughly knowledgeable about the information and the flow of information in an organization can effectively create application programs.

New Mexico Institute of Mining & Technology; Allan M. Stavely; ***Analysis Tools for Design-Level Assessment of Software Systems***; (MCS-8107756); $54,358; 24 mos.

The project will produce analysis tools which can be applied to software system description during the design phase of the system's development, to assess the acceptability of a proposed design before an implementation is attempted. The systems being designed may be either sequential or concurrent; in concurrent systems, message-passing and synchronization activity and possible orderings of significant events will be of particular interest.

Analysis techniques will be employed which analyze a system description's structure, its predicted behavior, and the relationships between them. The information obtained will be presented to the software system designer, who will use it to gain insight into properties of the system. Prototype implementations of already-existing analysis techniques will be built for experimental use. At the same time, fundamental research aimed at developing more powerful analysis techniques will continue, eventually leading to more powerful and useful tools. Since a design is a greatly simplified model of the eventual implementation, analysis domains for designs are likely to be simpler than for programs, and decision problems are likely to be easier. These and other benefits of abstraction during the design process will be exploited wherever possible.

University of New Mexico; Charles Crowley; ***Operating System Structure and Portability***; (MCS-8102296); $55,032; 24 mos.

Currently, there are two major philosophies of operating system structuring: procedure calling and message passing. The procedure orientation is currently more common and more popular since it is more efficient for a uniprocessor and fits in with current thinking about programming languages. The message orientation is more adapted to distributed systems and computer networks. The previous NSF-funded project resulted in a message based operating system running on the PDP11. (The kernel of the system also runs on a VAX11/780.) This system emulates the UNIX kernel and consists of a small kernel and several system processes. This

research has shown the message passing versions of (the strongly procedure-oriented) UNIX to be much slower than UNIX. Message passing becomes more natural and resource efficient in a distributed system. This will be investigated experimentally by porting the existing system to a multiple microprocessor system based on a common high-speed bus. The intent is to show that uniprocessor-based message passing systems port easily to a multiprocessor and that the resulting systems use the available resources efficiently and significantly outperform their uniprocessor-based equivalents.

Cornell University; Robert L. Constable and Alan J. Demers; ***On Logics for Program Development***; (MCS-8003349); $63,705; 12 mos. (Joint support with the Theoretical Computer Science Program & Software Systems Science Program-Total Grant $173,705).

This research involves the judicious combination of the strong points of program development methodology and program verification in a logic for correct program development. This project will explore a logic of formal top down development, called a refinement logic. During the grant period a prototype system will be designed and built. This system will be used in extensive experimentation of the refinement logic concept. Comparisons with other systems will also be conducted.

Cornell University; Richard W. Conway; ***Diagnostic Facilities and Interactive Program Development Systems***; (MCS-8003304 A01); $80,484; 12 mos.

One of the goals of this research is the development of a program development system by the adaptation of the error-repair philosophy of the PL/CS system to an interactive environment. Since the Program Synthesizer, which was also developed at Cornell University, has a different internal structure and presents a different interface to the user, there will be an excellent opportunity to compare the two approaches. Error-repairing processors have been in use for several years but there has never been any serious evaluation of their performance. Another goal of this project is to perform an experimental evaluation of error-tolerant methods of program development.

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# Intelligent Systems

## Computer Vision and Image Processing

Purdue University; King-Sun Fu; ***Workshop on Structural and Syntactic Pattern Recognition***; (ECS-8109620); $11,600; 12 mos. (Joint support with the Automation, Bioengineering, & Sensing Systems Program-Total Grant 23,300).

This action supports a workshop on Structural and Syntactic Pattern Recognition. The purpose of the workshop is to invite experts from both academic institutions and industries to assess the progress in structural and syntactic pattern recognition in terms of its contributions and limitations to practical applications and to project the future directions of this area.

Structural information has been regarded as very important in pattern analysis. Only within the last ten years, systematic methods have been developed to handle the representation and analysis of pattern structures. Practical applications of structural and syntactic pattern recognition include character recognition, ECG and EEG analysis, fingerprint identification and classification, LANDSAT data interpretations, machine part recognition, and automatic inspections.

University of Maryland; Azriel Rosenfeld; ***Workshop on Human and Machine Vision, August 17-19, 1981, Chicago, Illinois***; (MCS-8108445); $20,000; 6 mos.

A three-day workshop will be held which will bring together leading researchers in the fields of computer vision and human visual perception for exchange of ideas. Topics to be covered in half-day sessions include segmentation, representation, form, texture, space, and motion. On each topic there will be two main speakers, one each from the human and computer sides of the subject, as well as two or more discussants who will supplement the speakers' viewpoints. Book publication of the proceedings is planned. This workshop will provide a unique opportunity for communication between workers in the two fields, who generally do not follow each other's literature closely, and hardly ever attend the same meetings, so that typically their concepts of each other's work are many years out of date. Existing meetings and workshops involve workers in one field or the other, but not both.

University of Maryland-College Park; Azriel Rosenfeld and Dianne P. O'Leary; ***Representation and Control in Computer Vision: Multilevel Relaxation Approaches***; (MCS-7923422 A01); $108,000; 12 mos. (Joint support with the Automation, Bioengineering, & Sensing Systems Program-Total Grant $140,413).

Computer vision can be regarded as a process of establishing a correspondence between specific relational information derived from a scene and general relational information defining a model for a class of scenes. Computer vision systems make use of three types of data structures—arrays, region or object representations, and relational structures. In analyzing a given scene, information is discarded when passing from one representation to another. Multiple-resolution representations such as "pyramids" will be used to make this process more selective. They will also provide new ways of modeling shape and geometry, and of introducing information about them into the array-level processing.

The process of finding correspondences involves a potentially combinatorial search. Many "smart" search techniques exist, but parallelism provides the best possibility for speedup. Relaxation" methods iteratively apply local constraints in parallel to reduce the size of the search space. Experiments on a variety of problems have shown that these methods are robust. A Bayesian basis for relaxation has recently been developed. Relaxation methods are being successfully extended to multiple, multilevel processes. The conditions under which these relaxation methods work are more fully understood as a result of these investigations.

Massachusetts Institute of Technology; Whitman A. Richards; ***Natural Computation and Control***; (MCS-7923110 A01); $121,972; 12 mos (Joint support with the Division of Information Science & Technology and the Air Force Office of Scientific Research-Total Grant $411,972).

Research in natural computation explores the information processing mechanisms utilized by biological systems in performing basic sensory and motor functions. The MIT effort is primarily concerned with understanding the computational mechanisms which underlie the human visual system's representations of the external world. Topics to be investigated will include: (l) stereopsis, (2) texture, (3) structure from motion , (4) transparency, (5) color perception and normalization, and (6) derivation of object shape from contour and shading.

University of Massachusetts; Edward M. Riseman; ***A Computer System for Visual Interpretation of Natural Scenes***; (MCS-7918209 A02); $124,600; 12 mos.

The long-range objective of this research is to automate the analysis and interpretation of imagery. The approach is to incorporate a-priori knowledge about the environment into a computer system (VISIONS) which combines the high-level a-priori knowledge with low-level scene segmentation algorithms, and produces analyses and descriptions of the objects in the scene. The use of perspective, 2D and 3D schemas are part of the primary research thrust.

Michigan State University; Carl V. Page; ***A Study of Augmented Relaxation Labeling for Parallel Image Understanding***; (MCS-8004126 A01); $35,116; 12 mos.

The theoretical concept of augmented relaxation process has been defined with the aid of practitioners of image understanding. A recent Ph.D. thesis has extended this definition. Theoretical consequences of this definition will be studied with an eye to the development of parallel algorithms for image understanding. In particular, controlled processes which coordinate the interaction of global and local information will be studied by means of stochastic automata and stochastic languages. Key questions concern the generality of the methods, their stability and how amenable they are to parallel processing. A few experiments will be run on well-understood data to sharpen the definitions and verify results. A novel aspect of this work is that both top-down knowledge and bottom-up knowledge interact via a probability distribution over image descriptors.

Wayne State University; Ramesh Jain; ***Dynamic Motion Analysis***; (MCS-8100148); $67,183; 24 mos.

Motion analysis or the detection of movements of objects in a scene is an important area in computer vision research. This research effort will investigate the following topics in this area.

1. Study difference picture based methods for the analysis of complex aspects of motion, i.e., occlusion and three-dimensional structure.
2. Develop methods for the extraction of motion information for given surfaces under known lighting conditions.
3. Develop fast algorithms for the computation of optic flow (velocity vector of image points).
4. Investigate methods for segmenting the frames of a real world dynamic scene obtained from a moving camera whose ego-motion is known.

The results of this investigation will facilitate the interpretation of biomedical, industrial and satellite images.

University of Minnesota; William B. Thompson; ***Disparity Analysis of Image Sequences***; (MCS-8105215); $55,124; 12 mos.

Image sequences can provide important information about the three-dimensional structure and dynamic behavior of objects in a scene. Changes in a sequence can be characterized by disparity-the translation between frames of image points corresponding to particular points on the surface of visible objects. Disparity analysis encompasses methods for determining disparity values and inferring scene properties from those values. A study of disparity analysis with the intention of improving accuracy and efficiency, increasing the number of image points for which disparity values can be found, locating occlusion boundaries, and inferring depth relationships at those boundaries will be made. Improvements in disparity determination will come from better utilization of spatial context and from the temporal information available in longer sequences. The estimation of three-dimensional structure will be based on spatial variablity of disparity values and on the accretion and deletion of occluded surfaces across image sequences.

Oregon State University; Kennan T. Smith; ***Mathematical Aspects of Divergent Beam Radiography***; (MCS-8101586); $18,699; 12 mos. (Joint support with the Applied Mathematics Program-Total Grant 37,398).

The underlying objective of this project is the extraction of information from radiographs through the use of mathematics and mathematical thought. The research takes two separate but highly dependent directions.

The first is a mathematical study, usually rather sophisticated, of the nature of the information contained in a finite number of radiographs of an object. This involves also, as the limiting case of a large number of radiographs, the study of the information contained in a countably infinite number.

The second is the investigation of new methods of extracting information from radiographs and the improvement of known methods, such as computed tomography. In this part of the research the mathematics is sometimes sophisticated, as in the description of the general relation between point spread functions and convolution kernels in tomography; sometimes elementary, as in the work on mammography; and sometimes almost nonexistent, as in the work on noise elimination. But mathematical thought is always present, and experiments are crucial. The basic ideas come mainly from experiments, and from mathematical thought about them.

University of Pennsylvania; Ruzena K. Bajcsy; *Scene Understanding Via Active Sensors*; (MCS-8106176); $25,000; 12 mos. (Joint support with the Automation, Bioengineering, & Sensing Systems Program-Total Grant $50,000).

This research deals with various issues in the representation of three-dimensional objects. The main emphasis will be on the geometric representation of objects, that is, their volumes, surfaces, edges, and corners. However, some other properties derived from the tactile sensor and from a topological point of view will also be considered. The relationships and transformations between the object-centered and viewer-centered representation will also be investigated. The results of this investigation will contribute to the development of computer vision systems.

Brown University; Ulf Grenander and Walter Freiberger; *A Theory of Patterns and Its Applications*; (MCS-7924983 A01); $98,999; 12 mos.

This research is directed toward extending and completing the mathematical theory of regular structures (pattern theory) and applying this theory to specific problems in physics and biology. Application areas to be considered include:

1. the structure of scientific inference
2. computer tomography
3. image restoration
4. biological growth models
5. morphogenesis
6. mathematical semantics
7. social domination patterns
8. neural networks.

Virginia Polytechnic Institute; Linda G. Shapiro and Robert M. Haralick; *Structural Matching and Geometric Reasoning for Object Classification*; (MCS-8102874); $60,014; 12 mos.

This research plan for object classification from digital imagery consists of: 1) using the facet model for low level segmentation; 2) using sensing physics and domain specific knowledge to group raw segmented regions into meaningful surfaces; 3) using a relational data structure for representing both the two-dimensional image regions with their properties and the three-dimensional models of the various object types; 4) using a database that is organized into possibly overlapping clusters of three-dimensional object models, where objects in a single cluster have similar structure and similar attributes, and 5) using a combination of structural matching and geometric reasoning to determine which kind of objects having three-dimensional relational models in the database could have produced perspective projections that led to the two-dimensional relational structures extracted from the image.

The results of this research will be useful in automated assembly, automated inspection, and robot vision.

University of Wisconsin-Madison; Frank Scarpace; *Applying Recursive Cue/Model Hierarchies to Schemata Based Computer Vision*; (MCS-8004882 A01); $27,444; 12 mos.

A major problem in model-driven vision systems is the invocation of appropriate models to interpret a given image. Typically, data-driven methods are employed to generate low-level image cues to select likely models as hypotheses. It has been pointed out that this method is ineffective. Low-level cues are highly ambiguous; matching to many inappropriate high-level models.

As a solution to this problem, we propose to integrate model-driven and data-driven recognition in schemata representations by employing a recursive hierarchy of cues and models. Schema models are invoked both by primitive cues computed directly from the image and by abstract cues created recursively as the result of recognition. The successful recognition of a schema instance at one level in the hierarchy yields a context-sensitive cue to invoke schema models at higher levels.

These methods will be applied to understanding hand-drawn sketch maps and to automatically classifying urban aerial photography. This second application should be of significant assistance to remote sensing research in the automatic prediction of urban pollution from sediment run-off.

## Natural Language and Signal Understanding

Stanford University; John Chowning (in collaboration with Cordell Green, Systems Control Inc.); *Industry/University Cooperative Research: Intelligent Systems for the Analysis of Digitized Acoustic Signals*; (MCS-8012476 A01); $39,281; 12 mos. (Joint support with the Industry/University Cooperative Program-Total Grant $94,470).

The objective is to undertake research in developing methods and techniques for analyzing and understanding digitized acoustic signals. The goal will be to more formally characterize the nature and characteristics of acoustic signals and to explore the use of artificial intelligence and signal processing techniques in accomplishing and partially automating the task of this analysis. The approach will be to develop a knowledge-based signal understanding system that will input a digitized sequence of acoustic signals. The system will produce a characterization of the sound in the form of a "map"—a representation of the sound that involves not only an indication of the acoustical elements and processes presented, but will also provide information about timing, source identification, pitch and loudness features, and complex signal stratification.

Systems Control Incorporated; Cordell Green (in collaboration with John Chowning, Stanford University); *Industry/University Cooperative Research: Intelligent Systems for the Analysis of Digitized Acoustic Signals*; (MCS-7923282 A01); $39,683; 12 mos (Joint support with the Industry/University Cooperative Program-Total Grant $95,437).

The objective is to undertake research in developing methods and techniques for analyzing and understanding digitized acoustic signals. The goal will be to more formally characterize the nature and characteristics of acoustic signals and to explore the use of artificial intelligence and signal processing techniques in accomplishing and partially automating the task of this analysis. The approach will be to develop a knowledge-based signal understanding system that will input a digitized sequence of acoustic signals. The system will produce a characterization of the sound in the form of a "map"—a representation of the sound that involves not only an indication of the acoustical elements and processes presented, but will also provide information about timing, source identification, pitch and loudness features, and complex signal stratification.

Haskins Laboratories, Inc.; Franklin S. Cooper; *Verification of Syllable Hypotheses in Automatic Phonetic Analysis of Spoken English*; (MCS-7916177 A01); $114,931; 12 mos.

Automatic phonetic analysis of fluent speech is an essential component of computer speech-processing systems. Dealing successfully with fluent speech requires that the system make use of knowledge about the language (top-down processing) as well as parametric representation of the speech waveforms (bottom-up processing). At an intermediate level, the parametric representation is segmented and categorized into a sequence of symbols and words, resulting in a drastic reduction in the information rate. This research is focussed on the problem of parameter-to-symbol transformations.

Duke University; Bruce W. Ballard; *Natural Language Interfaces to "Layered" Domains: A Multiple-Prototype Approach*; (MCS-8116607); $31,598; 24 mos. (Joint support with the Division of Information Science & Technology-Total Grant $62,598).

Although recent years have seen important advances in artificial intelligence and computational linguistics, many problems remain to be solved before the goal of truly "natural" language systems is achieved. This research will study the class of "layered" domains, which contains many problems of interest and whose semantics and domain structures resemble previous work by the author. Assuming the context of question-answering, two particularly timely issues in natural language system design will be addressed.

1. How can several of the more difficult context-related problems of natural language be handled together in a single system?
2. How can a prototype be built so that applications to new domains can be made quickly, yet without loss of reliability?

To enforce a firm distinction between general and domain-specific aspects of an implementation, three prototype systems will be designed simultaneously for different layered domains. This research is expected to contribute both to theories of natural language understanding and in the area of reliable system design.

New York University; Ralph Grishman; *Natural Language Interfaces Using Limited Semantic Information*; (MCS-8002453 A01); $68,300; 12 mos.

Natural language interfaces to computer systems offer the potential for directly processing the information in technical and scientific texts and for making computer systems readily accessible to a much wider group of users. A major problem in designing a compact, portable natural language interface has been the need to incorporate sufficient background information to permit the correct analysis of sentences in a particular domain. For many domains, it is not practical to collect all the information known to a potential user. This raises the question: is there a small subset of domain-specific information adequate for analyzing a sufficient fraction of the sentences to make the inferface usable? This research project will investigate one possible subset, a description of the structure of the information in a domain. This description, called a domain information schema, consists primarily of a classification of the objects in the domain and the possible relations between these objects. The adequacy of the domain information schema as a source of domain-specific knowledge will be tested on two existing natural language interfaces. This will require several extensions to current techniques in computational linguistics in order to maximize the use of the domain information schema. The interfaces will be applied to substantial texts, specifically medical records and corresponding queries; the success and failures of the interfaces will then be analyzed to assess the adequacy of the proposed domain information schema.

Carnegie Mellon University; Raj Reddy; *Learning and Knowledge Acquisition in Speech Understanding*; (MCS-7825824 A02); $122,327; 12 mos.

Speech understanding involves complex tasks in signal learning and symbol learning. This research is directed toward discovering computer-based techniques for knowledge acquisition and learning, to deal with the following problems in speech understanding by machine: (1) new environments, (2) new speakers, (3) new words and grammatical constructs, and (4) new task domains.

University of Pennsylvania; Aravind K. Joshi; *Research in Natural Language Processing*; (MCS-8107290); $120,013; 12 mos.

This research project is concerned with several major areas in natural language processing dealing with several aspects of cooperative behavior in the context of question-answer systems, and addressing certain key issues in man-machine interactions through natural language. In particular, the project will investigate (1) cooperative responses for correcting misconceptions about the structure of the data base and for dealing with dynamic data bases, (2) the natural language generation of descriptions and explanations in question-answer systems, and (3) the role of mutual beliefs in question-answer systems. Other parts of the research deal with some issues in control of inferences and relationship of grammars to parsing strategies, both of which involve study of some formal systems.

## Automatic Theorem Proving and Inference

Stanford University; John McCarthy; *The Mechanization of Formal Reasoning*; (MCS-7905998 A02); $104,329; 12 mos.

The objective of this project is to develop a common representational formalism and deductive system for mechanizing a variety of tasks involving reasoning. The approach is based on the FOL system developed by Dr. Richard Weyhrauch at the Stanford A.I. Laboratory. The researchers will address such diverse problems as: reasoning about actions, beliefs, and knowledge; perception and control of actions; and verification of hardware designs by a formal proof method. The investigation will include an examination of conditions under which reasoning at a meta-level provides more efficient solutions to problems than reasoning at the object-level.

Stanford University; Patrick Suppes; *Interactive Theorem Proving*; (MCS-8011975 A01); $89,754; 12 mos.

This project will pursue research on mechanical theorem-proving in EXCHECK—a goal-structured, interactive, proof-checking system used to teach logic and set theory to approximately 300 students each year at Stanford University. Our major goal is to shift the emphasis of the EXCHECK system from a primarily logical analysis of set-theoretic notions to a more mathematical framework through

the introduction of natural mathematical notions in both the internal algorithms of EXCHECK and its dialogue with the user.

Northern Illinois University; Ross A. Overbeek; *Topics in Automated Theorem Proving*; (MCS-7903870 A02); $31,750; 12 mos.

Over the last seven years a theorem-proving program has been developed at Northern Illinois University which has recently established answers to three open mathematics problems in Boolean algebras and semigroups. The current research will be directed towards the following goals:

1. expansion of the class of open mathematics problems that can be addressed by the system,
2. continuation of the work on paramodulation,
3. examination of capabilities of other theorem-proving systems (notably, that of W. W. Bledsoe at the University of Texas, Austin),
4. examination of a class of problems in Tarskian geometry which to date have defied solution by any theorem-proving system.

Northwestern University; Lawrence J. Henschen; *Automated Theorem Proving*; (MCS-7913252 A01); $51,819; 12 mos.

The objective of this research is to extend the theory of automated mathematical deduction using the formal language of mathematical logic. Two major problem areas will be investigated: (1) a new non-resolution technique involving the calculation of "covering terms" for determining the remaining permissible truth value assignments to clauses at each stage of the deduction; (2) incorporation of splitting rules for higher-order logic into the unification algorithm.

University of Illinois-Urbana; Ryszard S. Michalski; *Studies in Computer Induction and Plausible Inference*; (MCS-7906614 A02); $38,551; 12 mos.

Current methods of knowledge acquisition for knowledge-based expert systems require the laborious incorporation of human experts' knowledge of specific domains in a formal system, such as production rules. Professor Michalski's research in plausible inference provides an approach to automating this process of knowledge acquisition from empirical data. His approach has been validated in a series of successful experiments in automating the inference of diagnostic rules for plant pathologies. The objectives of the present project are the formulation of a comprehensive theory of induction and plausible inference based on the earlier work, and the development of computationally efficient algorithms for computer implementation of the theory.

Indiana University-Bloomington; Douglas R. Hofstadter; *Seek-Whence: A Project In Pattern Understanding*; (MCS-8009201 A01); $40,003; 12 mos.

SEEK-WHENCE is a research project in artificial intelligence, whose target is the mechanization of the processes involved in the detection of patterns in sequences, the discovery of the rules underlying those patterns, and the generalization of those rules to produce related sequences such as those to which people generalize the original sequence.

LeMoyne College; Neil V. Murray; *An Investigation into the Design and Implementation of a Prawitz-Based Theorem Prover*; (MCS-8103478); $28,124; 24 mos.

The goal of this research is to design and implement a predicate calculus theorem prover which, although based on the same foundation (Herbrand's theorem) that underlies most predicate calculus provers, will possess several novel design characteristics. This theorem prover will not do inference per se, but will search directly for a contradictory set of instances of the input formulas, which are required to be quantifier-free but whose truth-functional structure is totally unrestricted. An unexplored variation of Prawitz analysis will be employed, in which the maximal unifiable partitions of the atoms of a set of formulas are surveyed.

Carnegie-Mellon University; Peter B. Andrews; *Automated Theorem Proving in Type Theory*; (MCS-8102870); $44,051; 12 mos.

This research is directed toward enabling computers to construct and to check proofs of theorems of mathematics and other disciplines formalized in type theory (higher order logic) or first order logic, and to assist humans engaged in these tasks. Improvements will be made to an existing computer program which proves theorems by finding refutation matings embodying the essential logical structure of the theorems, and transforming the matings into natural deduction proofs. Matings induced by proofs will be studied, as a step toward a general theory of matings and proofs. Theory of matings will be extended from first to higher order logic.

Attempts will be made to design improved heuristics for constructing elegant proofs, and improved search strategies for finding refutation matings. Special attention will be paid to the problems of quantifier duplication and of avoiding redundant search

induced by symmetries. It is hoped that theoretical insights into the structure of matings will yield heuristics for instantiating higher order variables, and that knowledge about solvable cases of the decision problem can be integrated into the program.

Development will continue on the computer system as a practical and convenient tool for constructing and checking proofs interactively or semi-automatically.

University of Texas-Austin: Woodrow W. Bledsoe; *Research on Automatic Theorem Proving and Applications*; (MCS-8011417); $88,629; 12 mos.

This research is a continuation of present work in automatic theorem proving and its applications to program verification and mathematics. Earlier work has included the development of computer programs which: prove theorems as part of a program verification system; prove theorems from intermediate analysis with techniques for instantiating set variables and for handling general inequalities. Other work has been on complete sets of reducers and agenda driven provers. This investigation will continue the work, especially in program verification and complete sets of reducers, and in continuing the effort to build a more powerful general theorem prover.

## Knowledge Representation and Problem Solving

Stanford University; Edward A. Feigenbaum, Bruce Buchanan, Lawrence Kedes, and Douglas L. Brutlag; *MOLGEN: A Computer Science Application to Molecular Biology*; (ECS-8016247 A01); $39,946; 12 mos. (Joint support with the Computer Engineering Program and Biophysics Program-Total Grant $159,785).

The MOLGEN Program is a continuing collaboration between computer scientists and molecular biologists to develop computer methods for knowledge representation, symbolic inference, and other forms of advanced symbolic manipulation that are of importance to molecular genetics. A number of software packages have already been developed that are beginning to be widely used, and show great applications promise. The knowledge engineering techniques being developed in this project are applied to problems in synthetic molecular biology, specifically the cloning, sequence determination and analysis of biologically interesting regions of DNA. MOLGEN is a "software laboratory" in which to explore and test new concepts and methods of knowledge representation, knowledge base management and planning. The work under this grant significantly improves the extent and quality of the existing knowledge base in MOLGEN and introduces automatic methods for extending the knowledge base. These "learning" methods recognize when a MOLGEN generated plan for an experiment is worth preserving and then generalizes the plan appropriately so that it is useful over a wider class of situations than the one for exploring a wide range of questions of performance evaluation of applied intelligent systems. As intelligent systems science moves toward knowledge engineering, such questions take on increased significance for the design and test of future expert systems. Computer methods for assisting the planning of experiments also continue to be studied and developed. These involve experiment "debugging" and experiment plan optimization.

Stanford University; John McCarthy; *Basic Research in Artificial Intelligence*; (MCS-8104877); $71,019; 12 mos.

The long range goal of this research is a program that can be told facts about the world and can use them effectively to achieve the goals it is given. More specifically, this research will emphasize the structure of formal reasoning, epistemological problems of artificial intelligence and mathematical theory of computation. The mathematical theory of computation supports the artificial intelligence work by providing tools for reasoning about complex strategies and showing that they attain their goals.

Yale University; Drew McDermott; *The Representation of Spatial Information for Problem Solving and Understanding*; (MCS-8013710 A01); $41,801; 12 mos.

This research is concerned with representing spatial information for use in problem solving and other applications. It focusses on the use of "fuzzy maps" for representing regions of space and time. A fuzzy map is a map, consisting of several frames of reference, in which objects' positions are constrained by the facts assimilated so far. A generalization of this notion is to a fuzzy time tree, in which

events and objects are located with respect to several different possible futures. Making this work requires new research into setting up dependencies among events in the tree. What is learned will be applied to the design of a problem-solver for solving problems requiring run-time scheduling of processes occurring at various places.

Indiana University; Robert E. Filman; ***Meta-Reasoning in Knowledge Representation***; (MCS-8102291); $57,991; 24 mos.

A central issue in the creation of an intelligent computer system over a domain is the representation of the knowledge embedded in that domain in machine-useable forms. We believe that it is possible to construct intelligent systems where the underlying facts, the legal conclusions derivable from those conclusions can all be expressed in machine-usable form as instances of meta-theoretic reasoning.

This research will explore the expression and resolution of knowledge representation problems by a combination of procedural attachment, rewriting systems, and meta-theoretic representations, in the context of a first order logic system. Issues to be addressed include the representation of heuristics and control, hypothetical reasoning, non-monotonic systems, knowledge and belief, time strategies, learning and game-theory.

Massachusetts Institution of Technology; Gerald J. Sussman and Carl E. Hewitt; ***Computer Aided Evolutionary Design for Software Engineering***; (MCS-7912179 A01); $55,000; 12 mos. (Joint support with the Software Engineering Program-Total Grant $110,000).

Large software systems are generally associated with high cost and low reliability. These problems are not due primarily to sloppy programming or poor management, but rather are symptoms of the lack of technology for aiding software engineers in the process of evolutionary design. The fundamental issues involved in constructing an interactive computer aided design tool for software engineering will be investigated. The principles developed in this research should be applicable to the construction of similar aids for other engineering disciplines. Automatic program verification techniques now available form only part of the methodology necessary to provide powerful assistance to the designers and implementers of large systems. Verification techniques are most suitable for proving the correctness of algorithms. The complexity and evolutionary nature of software systems requires a number of additional techniques.

The evolutionary nature of large systems is partially due to the fact that simplifying assumptions must be made in order to come up with an initially feasible design. Unfortunately, such "first order" designs need to be debugged when the simplifying assumptions are relaxed. This calls for design aid techniques which deal effectively with changing and incomplete specifications.

The managing of complexity is a fundamental issue in all engineering disciplines. Identified are three major techniques used in more mature engineering fields such as electrical and mechanical engineering which seem applicable to the engineering of software systems, incremental modelling, multiple and almost hierachical decomposition, and analysis by inspection.

University of Massachusetts; Victor R. Lesser; ***Cooperative Distributed Problem-Solving***; (MCS-8006327); $79,000; 12 mos.

The major focus of this research is the exploration of a new model for distributed problem solving systems. The model's ability to handle the presence of inconsistent and incomplete information at the processing nodes will enhance the applicability of the distributed computing approach. The research effort will be directed at the development of:

1. Techniques for the measurement, diagnosis, simulation and mathematical analysis of distributed problem solving systems.
2. Mechanisms for distributed focus-of-control and planning.
3. Characterization of distributed algorithms in terms of the type of uncertainty in data and control they can resolve.
4. A distributed simulation facility using a color graphics display.

University of Michigan; Arthur W. Burks and John H. Holland; ***Formal and Interdisciplinary Studies of Adaptive and Computing Systems 1979-1982***; (MCS-7826016 A02); $60,000; 12 mos. (Joint support with the History and Philosophy of Science Program-Total Grant $66,243).

The Logic of Computers Group at the University of Michigan is engaged in the development of logical formalisms applicable to digital computing systems and to computer investigations of natural systems. These studies range through switching theory, deterministic automata, probabilistic logics, the formal theory of evolutionary and adaptive systems,

and the analysis of complex dynamic systems with multiple feedback loops. These systems occur in engineering, economics, biology, ecology, psychology and anthropology, and are not amenable to standard analytic techniques. The current work will emphasize development and application of adaptive systems and genetic algorithms, and continuation of research in the history of computation.

University of New Hampshire; Eugene C. Freuder; ***Constraint Satisfaction: Relating the Structure of the Problem to the Structure of the Solution***; (MCS-8003307 A01); $12,301; 12 mos.

Many search problems conform to the following general model: find values for a set of variables which simultaneously satisfy a collection of constraints. The eight queens problem, the graph coloring problem, the scene labeling problem, data base retrieval problems are among the many which fit this mold. Backtrack and constraint relaxation algorithms are used on these problems. Many are combinatorially explosive. Some heuristic techniques are available to improve search efficiency. More are needed. At present it is pretty much a matter of experiment or trial and error to determine when a given heuristic will be effective on a given problem. Results are required which tell us when to apply these heuristics.

Specifically, results are sought of the form: if the problem has structure A, solution method B has benefit C. In particular relationships are sought between the graph structure of constraint connections and the order in which constrained variables are chosen for instantiation. The central goal is to provide guidance in choosing a search technique appropriate to the task.

Rutgers University; Tom M. Mitchell; ***Improving Problem Solving Strategies by Experimentation***; (MCS-8008889); $87,836; 24 mos.

Heuristic problem solving programs represent some of the most useful products of research on intelligent systems. However, the sheer complexity of these programs poses a major barrier to improving their performance beyond a certain threshold. One approach to circumventing this complexity barrier is to develop methods by which a heuristic problem solver can automatically acquire expertise at solving problems in a given task domain.

A system will be developed that acquires aspects of its heuristic problem solving strategy through experimentation. The system will (l) propose practice problems, (2) attempt to solve them, (3) analyze the steps it performed in solving the problem, then (4) propose general control heuristics and macro-operators, designed to improve its performance on subsequent problems. In order to study general methods for acquiring heuristics and macrooperators, a computer program will be constructed that acquires expertise at a particular task: solving symbolic integration problems. This task domain is particularly appropriate for studying general methods in a concrete manner, since existing heuristic problem solvers in this domain provide a standard against which system performance can be evaluated.

State University of New York-Buffalo; Stuart C. Shapiro; ***Studies of Deductive Networks for the Representation of Knowledge***; (MCS-8006314 A01); $52,363; 12 mos.

Research will be conducted on the use of "monitors" (master processes which control the scheduling of other communicating processes) which have recently been developed for controlling and keeping track of subdeductions. We will investigate their use in determining when a successful subdeduction has no more results to report, in suspending an entire subdeduction when it is no longer needed, and in resuming a suspended subdeduction when it becomes useful for another deduction. We will investigate a way of representing a natural deduction system based on indexing each proposition with the set of initial assumptions it depends on. This method promises to liberate the notion of "contexts" from the hierarchical order of development it usually requires. We will investigate a method of combining the modes of reasoning forward from new data and backward from questions in a consistent and cooperative way which depends not on how rules are stored, but on how resources are allocated during read time and question time. We will continue our investigations into reasoning by the exception principle, and on the relative strengths of path-based and node-based reasoning.

State University of New York-Stony Brook; Herbert Gelernter; ***Computer-Directed Organic Synthesis Route Discovery***; (MCS-7816786 A02); $74,858; 12 mos.

SYNCHEM2 is a large scale computer program which uses heuristic graph-searching techniques to discover synthesis routes for complex organic molecular structures. The initial version of this program is currently running on the NIH/DCRT 370/168 computer in Bethesda, Maryland. Available to qualified users, it has attracted considerable attention in the pharmaceutical industry.

The current research program is focused on developing advanced heuristic graph-searching and problem-solving techniques to enable the system to calculate more complex molecular structures than are feasible under the computational limitations of the present system.

Ohio State University; B. Chandrasekaran; ***Knowledge Organization and Problem Solving for Diagnostic Tasks***; (MCS-8103480); $59,387; 12 mos.

An approach to knowledge organization and problem solving for expert systems which specialize in a certain class of tasks, viz., diagnosis will be investigated. The central ideas are: (1) knowledge is decomposed into a collection of specialists, each of whom concentrates in its knowledge about a relevant concept and (2) these conceptual specialists perform problem solving in parallel in certain specified ways, and use a blackboard as a record of the global state of problem solving. Several problems will be investigated including (1) how to coordinate the problem solving of lower level specialists, including deciding when to stop (2) development of a conceptual structure representation language which will make it easy to develop systems in different domains (3) study of temporal aspects of the diagnostic process and (4) multiple use of knowledge.

Temple University; Ranan B. Banerji; ***Flexibility and Efficiency of Knowledge Representation in Intelligent Information Systems***; (MCS-8110104); $40,000; 24 mos. (Joint support with the Division of Information Science & Technology-Total Grant $79,298).

An intelligent information processing program requires a knowledge base. Programs to carry out a very specific task may have the knowledge incorporated in the program itself, while intelligent programs capable of handling a wide range of problems have their knowledge stored in a versatile, complex data structure which the program has to process. This entails a trade-off between the flexibility of a program and its efficiency: versatile programs tending to be less efficient. The purpose of this research is to investigate as to how much of this trade-off is inherent and how much is avoidable. the initial phase will consist of comparing different question answering and learning programs by embedding the structures of their databases into one uniform structure of larger flexibility.

# Special Projects

## Data Handling, Data Manipulation, and Database Research

San Diego State University; Leland L. Beck; *Distribution-Dependent Dynamic Storage Allocation Techniques*; (MCS-8019973); $52,000; 24 mos.

The focal points of this project will be the analysis and design of storage allocation schemes with emphasis on data-driven, distribution-dependent techniques. Performance of current storage allocation and deallocation techniques will be studied through simulation. These results will lead to new and better approaches as well as extending and enhancing existing algorithms. These new methods will be designed to optimize generality and flexibility, and to give better performance over a wider range of conditions.

University of California-Berkeley; Alan Jay Smith; *Automatic File System Design and Optimization*; (MCS-7728429 A02); $45,200; 12 mos.

The recent introduction of commercially successful mass-store computer devices with more than a trillion bits of storage, and the expected introduction of gapfiller technology for a level of storage between main memory and disk have underscored our lack of understanding of hierarchical computer file system operation. This project will study automatic file systems, with the goals of understanding their use and optimizing their operation.

The plan is to measure several large computer systems and use the data collected to characterize file system operation and to create and validate models and optimization algorithms. The research is is concentrated in three broad areas:

1. To optimize the operation of automatic file systems;
2. To study the design and configuration of the memory hierarchy by using measured data; and
3. To characterize file access patterns and user behavior so as to predict the effect of anticipated changes in computer system technology.

Florida State University; Lois E. Wright-Hawkes; *Application of Simplified PG Decoding Techniques to Information Retrieval*; (MCS-8017047); $13,304; 18 mos.

One family of error correcting codes based on the properties of Projective Geometry (PG) codes has been found to possess certain structural characteristics, which allow the corresponding decoding process to be simplified by orders of magnitude.

It has been shown that combinatorial properties of PG's provide an excellent means of organizing data for information retrieval.

The purpose of this research is to apply the simplified decoding method to the retrieval of multi-attribute records stored using a PG format. With the rapidly growing number of large data bases, the necessity of simplifying retrieval procedures is increasing. The combination of simplified decoding techniques and information records stored using combinatorial algorithms, suggest a powerful solution to this topical problem.

University of Maryland; S. Bing Yao; *Design, Modeling and Performance of Data Base System*; (MCS-8107047 & A01); $131,387; 18 mos.

This effort to investigate the extensions and applications of the attribute-based database "Access Model" is divided into three areas: physical database design and optimization, query optimization, and logical database design.

In physical database design the Access Model will be used to evaluate storage structures and access paths for database organizations. The Access Model can also be extended to mutiple files to select the best processing strategy for query optimization.

Several tools for logical database design will be implemented including a design requirement sampling and verification subsystem, a design requirement database, and interactive design integration subsystem, and a design evaluation subsystem.

State University of New York-Albany; Richard E. Stearns; *Theory for the Design and Use of Concurrent Database Systems*; (MCS-7903770 A01); $26,788; 24 mos. (Joint support with the Theoretical Computer Program-Total Grant $51,788).

Concurrency controls for database systems will be studied. Both centralized and distributed systems will be considered with the main emphasis on distributed systems. One objective is to produce concurrency controls which are proven to work correctly and which allow as much concurrency as possible. A second objective is to develop theoretical models which capture the essence of the real problems. The theory will be directed toward establishing the fundamental limits of concurrent operation and toward creating designs which have maximum flexibility within these limits.

An investigation will be made into the possibilities of controlling concurrency at the database manager level instead of the physical database level. The relational model will be given special attention because of the highly structured nature of the data model and the query languages.

Work will be continued on a database system simulator capable of simulating proposed concurrency controls under various load conditions. The simulator will be used to evaluate the relative merits of different designs.

State University of New York-Stony Brook; Zvi M. Kedem; *Theory and Applications of Database Concurrency Control*; (MCS-8104882); $74,991; 24 mos.

Recent research has led to the development of non-two-phase locking protocols for controlling concurrency which assure correct results in a database without causing deadlocks. Such systems make no use of information about the operations performed by transactions on data entities, although they do use a priori information about the order in which transactions may access the entitites. If information of the former type is also used, concurrency may be increased, but deadlocks are more difficult to avoid. The investigators will study non-two-phase locking protocols for such "partially interpreted" systems, with the goal of using both semantic and syntactic information to increase concurrency and possibly also avoid deadlocks. They will also study mechanisms for removing deadlocks when avoidance is impossible or too costly. Methods for conditioning the structure of a database to assure proper accessing behavior of the transactions so that such protocols can be used, as well as new general means for allowing concurrent dynamic modifications of the structure of the database, will be sought. The performance of all mechanisms developed will be evaluated in order to ascertain their applicability to real database systems.

This is a collaborative project with with Professors Abraham Silberschatz and Donald Fussell of the University of Texas at Austin.

Brown University; Steven P. Reiss; *Practical Data-Swapping*; (MCS-8022242); $85,644; 24 mos.

As part of this research, the investigators are considering the practicality of using data-swapping to assure the confidentiality of statistical databases presented either in the form of micro-data or in the form of statistical taublations. Data-swapping is a technique that involves finding transformations of the original data which preserve a desired set of statistics. It is a very promising technique since the transformed data can be released without violating the privacy of any individual and since this data can be used for accurate statistical anaylsis. The research is designed to investigate applications to actual databases as a validation of the technique.

University of Texas-Austin; Abraham Silberschatz; *Theory and Applications of Database Concurrency Control*; (MCS-8104017); $100,001; 24 mos.

Recent research has led to the development of non-two-phase locking protocols for controlling concurrency which assure correct results in a database without causing deadlocks. Such systems make no use of information about the operations performed by transactions on data entities, although they do use a priori information about the order in which transactions may access the entitites. If information of the former type is also used, concurrency may be increased, but deadlocks are more difficult to avoid. The investigators will study non-two -phase locking protocols for such "partially interpreted" systems, with the goal of using both semantic and syntactic information to increase concurrency and possibly also avoid deadlocks. They will also study mechanisms for removing deadlocks when avoidance is impossible or too costly. Methods for conditioning the structure of a database to assure proper accessir.g behavior of the transactions so that such protocols can be used, as well as new general means for allowing concurrent dynamic modifications of the structure of the database, will be sought. The performance of all mechanisms developed will be evaluated in order to ascertain their applicability to real database systems.

This is a collaborative project with Professor Zvi Kedem of SUNY-Stony Brook.

University of Virginia; John L. Pfaltz; *Analysis of Multi-Attribute Retrieval Using Indexed Descriptor Files*; (MCS-8017779); $40,000; 24 mos. (Joint support with the Theoretical Computer Science Program-Total Grant $75,000).

The investigator will concentrate on the problem of effective multi-attribute access in very large data

bases, using "indexed-descriptor files". This technology has been shown to be comparable to binary tree (B-tree) and/or inverted files access in relatively static data bases; but with much more flexibility, and, in the case of inverted file organization, with lower storage overhead. However, its performance, in terms of retrieval and storage costs; in dynamic systems is not well understood. This is particularly true since its very flexibility introduces many independent parameters. Implementation and analysis of a dynamic access system is the primary goal of the project.

University of Wisconsin-Madison; Anthony C. Klug; *A Database Management System Having Multiple Views and Multiple Data Models*; (MCS-8102864); $71,010; 24 mos.

Database management systems (DBMS) supporting multiple views and multiple data models allow diverse classes of users to (simultaneously) interact with the same database. Thus, with such a DBMS high level management, programmers familiar with hierarchies, programmers familiar with relations, natural language users, and other classes could all use the same database. In addition each particular interface (language) can present to the user just that data which is needed. Unused data can be masked, and common interactions can be incorporated into the view.

In this research, an experimental DBMS will be built which will support (at least) five user languages, each having a general view facility. The mappings binding the user views to the central schema will be verifiable, and a module to do this verification will be constructed.

Novel algorithms will be needed in several parts of the system. For example, they will be needed to verify view mappings, to optimize statements coming from different user languages, and to control concurrency. Tableau techniques will be used extensively.

## Privacy and Security

Stanford University; Martin E. Hellman; *Data Security*; (ECS-7916161 A02); $14,200; 12 mos. (Joint support with the Electrical & Optical Computing Program-Total Grant $56,749).

This research program is concerned with increasing the understanding of the use of cryptography in data security. Public key cryptosystems and their relationship to digital signatures are being studied along with cryptographic systems with a high level of mathematical structure. Efforts are being devoted to the certification process by which a system is tested for weaknesses prior to being designated as secure. The study is directed to general methods, such as time-memory tradeoffs, and to specific cryptographic systems, such as the Federal Data Encryption Standard.

Purdue University; Dorothy E. Denning; *Data Security*; (MCS-8015484); $60,000; 24 mos.

Protecting confidential personal records in online, centralized databases from unauthorized disclosure or modification is a problem of wide interest today. Although the Bureau of the Census and other agencies have faced this problem successfully for years, many of their current techniques are not applicable to general purpose database systems.

This research will be aimed at the study of statistical techniques for data security. Particular emphasis will be given to the Random Sample Queries (RSQ) technique, which uses sampling to control disclosure. A major goal of the project will be to develop a theory and framework for access control applicable to a wide range of general database systems.

Purdue University; Lawrence Snyder; *Secure Computation*; (MCS-8103139); $36,497; 12 mos.

This project, a collaborative effort with Anita Jones of Carnegie-Mellon and Richard Lipton of Princeton, is a continuation of work begun under MCS-7712517. As part of this research, the investigators will continue to study capability-based protection systems. The effort will follow four avenues of investigation:

1. Levels of Security
2. Aggregated Protection Rules
3. De Facto Transfers
4. Algorithmic Issues

All of these are issues which arise when security and protection techniques are studied for operating systems and databases. Emphasis will be on extending the Take/Grant protection model to solve these problems.

Rutgers University; Naftaly Minsky and Abe Lockman; *Protection of Information Systems*; (MCS-8009811 A01); $71,284; 12 mos.

This research is a continuation of current efforts to develop a protection scheme suitable for a wide variety of large scale information systems. Starting with the previously developed Operation Control scheme, the investigators plan to augment their scheme, working towards the following broadly defined goals: a) development of analysis of techniques which can answer questions about the policy being supported by a given protection state of a system; b) optimization of the representation and enforcement of policies; c) augmenting the expressive powers of our scheme's constructs to enable the protection of the highly dynamic processes of system building and modification; d) development of a useful methodology for mapping informal statements of desired policies into formal protection constructs.

Carnegie-Mellon University; Anita K. Jones; *Secure Computation*; (MCS-8103044); $27,567; 12 mos.

The major emphasis of this research will be on object oriented addressing and protection mechanisms as the basis for building secure computer systems. These mechanisms remain a most promising basis for the implementation of secure systems. In particular, capability addressing provides the basis for subdividing memory into small units, each of which is (dynamically) made addressible by an executing process for only the duration that it is needed by that process. Second, because objects have type, their behavior is restricted to be within the range of behavior that makes sense for that type; such restrictions are the basis for discipline in software development and maintenance.

A second area of investigation will include concurrency in distributed data bases, particularly emphasizing the maintenance of consistency of data in the face of concurrent updates, while maximizing the concurrency of computation.

This project is a joint effort with Professor Richard Lipton of Princeton and Professor Larry Snyder of Purdue.

Southern Methodist University; David L. Wells; *Navigation and Performance Questions in Encrypted Data Bases*; (MCS-8107479); $36,581; 24 mos.

In the past several years, a considerable effort has been expended in the development of encryption systems. The most suitable for data base applications is the so-called "subkey" scheme, although other methods such as the public-key system also have attractive properties. The existence of these cryptographic algorithms has made the use of encryption as a database protection mechanism a possibility.

In order to use encryption for data base protection, certain details of how to apply an encryption algorithm to a database must be resolved. The purpose of this research is to determine which portions of a data base system's relational and navigational information must be encrypted, how to navigate through encrypted indices and pointers, and the expected performance effects of encryption. Solutions to these problems will show the extent to which encryption can be used as a data base protection mechanism.

University of Wisconsin-Milwaukee; George I. Davida; *Data Security*; (MCS-8112345); $43,737; 12 mos.

This is a continuation of work on data protection. Emphasis will be on the use of cryptosystems in the design of secure operating systems and secure databases. Distributed computer architectures along with encryption will be investigated to determine the level of security that can be achieved. In databases, an algebra for encrypted relational databases will be investigated.

## The Societal Impact of Computing

New Jersey Institute of Technology; Murray Turoff; *Computer Based Conferencing*; (MCS-7800519 A03); $203,274; 12 mos.

A wide-ranging set of research issues in Computer-Based Conferencing (CBC) will be explored at the Computer Conferencing and Communications Center.

Work will concentrate on the following areas:

1. The development of software and hardware capabilities to further the state of the art in the design and engineering of CBC systems. Emphasis will be on user interface languages, messaging structures, and the incorporation of microprocessors in a conferencing network.
2. Controlled experiments on the effects of CBC on human communication. These studies will explore the impact of user interfaces and system facilities on the utility of CBC.
3. Applicationand evaluation experiments, laboratory and field trials. The interpretation of

their results will provide guidelines fo future applications of CBC and for the future development of software tools for group communjcation and problem solving processes.

New York University; Henry C. Lucas; ***Computer Based Information Systems and the Organization***; (MCS-8012911); $52,548; 18 mos.

This research deals with the management of information in organizations from three views:

1. The function and role of information in the organization;
2. Technological aspects;
3. The control of information as a focus of power in the organization.

The research design includes the collection of empirical data from a sample of manufacturing plants. Interviews and questionnaires are completed by the corporate systems staff, the plant information systems staff, the chief executive at the plant, department managers in five departments, the production manager, user and the personnel department.

The first component of the study examines questions of the location of computer equipment and the centralization and decentralization of information and computer mangement. Hypotheses are presented which must be tested with the data collected in the research. The second part of the research focuses on earlier work on the impact of computers on organizations. The final part of the effort deals with power relationships within the organization. Hypotheses are presented based on a theory of interdepartmental power and will be tested with the data from the study.

## Modelling & Simulation

Massachusetts Institute of Technology; Edwin Kuh and Roy E. Welsch; ***The Reliability of Economic Models***; (MCS-7726902 A05); $150,432; 12 mos. (Joint support with the Measurement Methods & Data Research Program-Total Grant $250,432).

This project is to support a central networking resource for research in computer model validation. The Computer Research Center will conduct research on error and model assumptions and on time series reliability analysis, and will maintain a software facility for modeling research based on the TROLL modeling language. Other funded researchers will tie into the project over a communications network, using a common software laboratory, exchanging programs and coordinating their research over a computer conferencing network.

Research in error and model assumptions will concentrate on developing reliability procedures to test the validity of theoretical assumptions underlying the algorithms in econometric models. Time series reliability anakysis will study reliability problems with regression relations and systems of stochastic equations.

This research will provide vitally needed insight into the reliability and validity of computer-based econometric models.

Washington University; Mark Franklin; ***Continuous Systems Simulation on Multiprocessor Systems***; (MCS-7820731 A02); $77,148; 12 mos. (Joint support with the Computer Systems Design Program-Total Grant $117,148).

The principal goal of this project is to increase significantly the solution speed and reduce the costs associated with continous system simulation on computers. The principal vehicle for achieving this goal is the exploitation of multiple processor computer architecture, in particuarl architecture based on Very-Large-Scale-Integration Technology (VLSI).

The research will be conducted in three main areas:

1. Algorithms, parallel integration methods and higher order numerical problems associated with simulation.
2. Systems architecture, quantifying hardware and software design parameters and system performance metrics.
3. Systems building and research tools development, development of a systems workbench on which new ideas of structure and algorithms can be tried.

## Networking, Computer Communications & Distributed Computing

Massachusetts Institute of Technology; Robert Gallager; *The Dynamics of Data Network Research*; (ECS-7919880 A01); $31,000; 12 mos. (Joint support with the Electrical & Optical Computing Program-Total Grant $116,000).

The objectives of this research are a) to develop new models and conceptual approaches for studying the multi-faceted problems of the distributed control of data communication networks, b) to develop and apply new algorithmic and analytical techniques for solving the problems formulated above, c) to synthesize these solutions into a better understanding of the underlying tradeoffs that exist in the engineering of efficient, reliable networks, and d) to use data networks as an example to contribute to a better understanding of the common problems that arise in controlling large scale distributed systems. The research focuses on the nature of, and the encoding of, the inter-nodal control information (i.e., the protocols) used to accomplish transfers of data in the network. Distributed algorithms for routing and flow control, and the systematic development of building blocks for such distributed algorithms is being considered.

University of Texas-Austin; Simon S. Lam; *Resource Allocation for Computer Communication Networks*; (ECS-7801803 A02); $25,000; 24 mos. (Joint support with the Electrical & Optical Computing Program-Total Grant $100,440).

Resource allocation techniques and their implementation in a distributed network environment are being investigated. Networks based upon virtual channels are currently the dominatnt packet networks. A new model is used to study the performance of these networks. Specifically, problems of congestion control, routing, aid-to-aid flow control, and the effect of their interaction on network performance are being examined. Techniques for synchronizing network status information in both broadcast and non-broadcast networks, and scheduling in broadcast networks with limited synchronization are being sought. A hierarchial model is being used to develop methods to analyze communication protocols.

## Other Projects, Symposia, Colloquia, and Studies

Stanford University; Gene H. Golub; *Workshop on Computatinal Problems in Complex Analysis, Palo Alto, California, August 31-September 4, 1981*; (MCS-8113489); $2,600; 06 mos. (Joint support with the Special Projects Program-Mathematical Science Section-Total Grant $5,200).

During the week of August 31-September 4, 1981, an informal workshop on "Computational Problems in Complex Analysis" was held at the Computer Science Department, Stanford University. The aim of this meeting was to bring together a diverse group of mathematical scientists, both in academics and industry, to exchange ideas in this growing field; and in addition, to help stimulate recognition of the importance of computational complex analysis in the United States, where it has received too little attention. The meeting was focused in part on a series of expository lectures by Professor Peter Henrici of the Swiss Federal Institute of Technology in Zurich, the leading figure in this field, and in part on presentations and informal meetings by the participants.

National Academy of Sciences; James R. Smith; *International Conference on Planning, Architecture and Computers (PArC 81), Washington, D.C., October 6-8, 1981*; (MCS-8112863); $5,000; 12 mos. (Joint support with the Water Resources & Environment Engineering Program-Total Grant $10,000).

A second International Conference on Planning, Architecture, and Computers (PArC 81) will be held in Washington, D.C. October 6-8, 1981. Emphasis of the conference will be on research topics directed at improving the productivity of those engaged in building and construction. In particular, the conference themes will concentrate on the role of more cost effective computers and systems in design and planning functions to support architects and builders.

Massachusetts Institute of Technology; Edward Fredkin; *Conference on Physics of Computation; Boston, Massachusetts; May 6-8, 1981*; (MCS-8108755); $3,000; 6 mos.

The MIT Laboratory for Computer Science sponsored a conference on "Physics of Computation," held on May 6, 7, and 8, 1981, at the MIT Endicott House, Boston. The conference was chaired by

Edward Fredkin (MIT Laboratory for Computer Science) and Rolf Landauer (IBM Thomas J. Watson Research Center).

The format of the conference encouraged intense interaction between a number of selected people who have had key ideas in this area or who were able to offer significant contributions to the discussion.

The conference explored the intimate connections between actual physics—especially at the fundamental and/or microscopic level—and computational processes. Bringing together ideas from computation and physics may contribute to a greater understanding of both. A major topic was the possibility of implementing computers that exploit in a more direct and efficient way the computational resources offered by the laws of nature.

Massachusetts Institute of Technology; Roy Kaplow; ***New Interactive Computer-Use Strategies Based on the Enhanced-Input Terminal System***; (MCS-7804755A02); $45,000; 12 mos. (Joint support with the Software Engineering Program-Total Grant $90,000).

A new type of computer terminal has been developed with enhanced capabilities for user input, including: user-defined, potentially unlimited symbol set; user-defined, free-format, touch-activated keyboards; and dynamically changing, software and user-controlled keyboard presentations which follow task progression. The terminal is based on graphical display device on which any keyboard design can be displayed instantaneously. This project will extend and examine the reach of this new environment for computer interaction through a two-faceted project. First, it will establish broad, affordable and more varied access through distribution over an existing two-way cable-TV network, and second, it will explore the impact of this new user/computer/video interface through study of usage patterns and through research on new languages and language concepts which the system makes feasible.

Such interfaces may have significant impact on the use of computers by non-experts, and by persons with mental or physical disabilities.

Institute of Electrical & Electronic Engineers; Allen Gersho; ***IEEE Communications Security Workshop: August 24-26, 1981; Santa Barbara, California***; (ECS-8117145); $3,200; 6 mos. (Joint support with the Theoretical Computer Science Program and the Electrical & Optical Computing Program-Total Grant $10,000).

The IEEE Communications Security Workshop was held on August 24-26, 1981 at the University of California, Santa Barbara, California. The objective was to delineate the state-of-the-art and future directions of research relating to the protection of the integrity, confidentiality and authenticity of electronically-communicated information , including cryptography, voice scrambling, and network security. Technical areas which received attention included cryptographic theory, key management, system implementation techniques, and standards and protocols.

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# Computer Science Research Equipment

University of Arizona; David R. Hanson; *Computer Science Research Equipment*; (MCS-8105764); $158,278; 12 mos (Joint support with the Software Systems Science Program, Computer Systems Design Program, and the Software Engineering Program).

A large minicomputer is being obtained to support research in the following areas:

1. High-Level Programming Language Facilities for Data Structure Processing;
2. Generalizing Command Languages and Utilities;
3. Software Testing;
4. Geobase Information Systems for Surface Climate Models; and
5. Distributed Processing: Language Mechanisms and Programming Techniques.

Stanford University; Jeffrey D. Ullman; *Computer Science Research Equipment*; (MCS-8106189); $150,000; 12 mos (Joint support with the Software Systems Science Program, Software Engineering Program, Intelligent Systems Program, and the Special Projects Program).

Two large scale minicomputers are being purchased to support research in the following areas:

1. Robotics,
2. High quality document preparation systems,
3. Database Systems, and
4. Numerical Analysis.

University of California-Irvine; Julian Feldman; *Computer Science Research Equipment*; (MCS-8105911); $150,000; 12 mos (Joint support with the Theoretical Computer Science Program, Software Engineering Program, Intelligent Systems Program, and the Special Projects Program).

This grant supports the purchase of three large minicomputers to enhance research in the following areas:

1. Programming Environments
2. Artificial Intelligence
3. Learning Control Knowledge for Problem Solving
4. Algorithms and Complexity
5. Resuable Software Engineering
6. Social Impacts of Computing.

University of Southern California; Melvin A. Breuer and Alice C.Parker; *Computer Science Research Equipment*; (MCS-8105901); $50,507; 12 mos (Support from Computer Systems Design Program).

This grant provides partial support for a high-resolution color graphics system to support research in the following areas:

1. Computer Aided Design of Digital Systems;
2. Layout of VLSI Circuits;
3. High-level fault models and test generation; procedures for VLSI and VHSIC technology;
4. Pictorial Program Construction; and,
5. Integrated Database Design.

University of Illinois-Urbana; William J. Kubitz; *Computer Science Research Equipment*; (MCS-8105759); $85,900; 12 mos (Joint support with the Computer Systems Design Program and the Software Engineering Program).

This grant provides partial support of a high resolution, refreshed, raster, color graphics display system for support of research in the following areas:

1. Synthesis of Computer Structures;
2. Automated Array Logic Design;
3. Logic Design Methods for Integrated Circuits; and,
4. Automated Management of Software Production.

New York University; Malcolm C. Harrison; *Computer Science Research Equipment*; (MCS-8106882); $147,000; 12 mos (Joint support with the Theoretical Computer Science Program, Software Systems Science Program, Software Engineering Program, and Intelligent Systems Program).

A large minicomputer system is being purchased to support research in the following areas:

1. Special Purpose Languages; Proof Verification Techniques,
2. Automatic Learning of Control in Production Systems,
3. Software Prototyping: The NYU-Ada System; and
4. Research in Computational Linguistics.

University of Texas at San Antonio; Cedric V. Armstrong; *Computer Science Research Equipment*; (MCS-8105902); $37,184; 12 mos (Support from the Computer Systems Design Program).

A parallel processing computer system will be assembled to support research in the following areas:

1. The use of Microprogrammed Control Structures in Parallel Systems Suitable for VLSI Implementation.
2. Quantitative Evaluation of Distributed Computer Systems.

University of Utah; Lee A. Hollaar and Richard F. Riesenfeld; *Computer Science Research Equipment*; (MCS-8105757); $145,000; 12 mos (Joint support with the Computer Systems Design Program, Software Engineering Program, and the Intelligent Systems Program).

A large minicomputer, graphics display system, and local network interconnections will be obtained to support research in the following areas:

1. Applicative Multiprocessor Systems
2. Computer Aided Geometric Design
3. Portable LISP-based Systems
4. Architectures for Full-Text Information Retrieval
5. Digital Signal Processing
6. VLSI Design.

University of Wyoming; David E. Winkel; *Computer Science Research Equipment*; (MCS-8106203); $13,890; 12 mos (Joint support with the Computer Systems Design Program and the Intelligent Systems Program).

Logic Analyzer and ROM Programmer units will be obtained in support of the following research projects:

1. A machine for the direct execution of the FORTH language.
2. Directed architectures for applicative languages.
3. Developing and testing hardware related to cybernetics and robotics research.

# Coordinated Experimental Research

## Experimental Computer Research

Yale University; Martin Schultz, Alan Perlis, and Roger Schank; *An Attached Processor Systems Laboratory*; (MCS-8106181); $574,152; 12 mos.

This award will aid in the establishment of a major experimental facility to support research in numerical analysis, scientific computing, algorithms, array processing, computer architecture, artificial intelligence, natural language processing, and systems programming. These new resources will enhance their computational capability and overcome address-space limitations which restrict their natural language research. They will also add a powerful array processor to support scientific computing and specialized processors for the LISP programming language. All these resources will communicate over a high bandwidth network, while terminal access will be provided through a switching network.

The completed local network of sophisticated computing resources will support cooperative research among three major research groups: the systems programming group, the scientific computing group, and the artificial intelligence group. The scientific computing group will concentrate on new algorthims and architectures, such as attached processors, to find ways to dramatically increase the scale of problems which can be considered for computer solution. The artificial intelligence group will pursue studies of integrated understanding and memory by modelling human memory organization and search strategies. Besides pursuing interests in distributed computing, the systems programming group will make major contributions to the others by bringing their experience to bear on the problems of supporting attached processors and implementing interactive problem understanding environments.

University of Illinois-Urbana; David Kuck; *A Computer and Software Systems Design Laboratory*; (MCS-8105896); $833,089; 12 mos.

This award will aid in the establishment of a major experimental facility to support research and development of computer aids to the design of computer and software systems. The project will result in the development of methodologies, techniques and software for supporting various aspects of computer science research. Joint studies by computer science researchers of various backgrounds will be facilitated.

The facility will expand on current departmental resources adding three major computational resources and a supporting high bandwidth network to interconnect the current and new resources. Highly interactive access will be provided through user interfaces and a switching network. Terminals can be directly connected to a particular resource through the switching network while user and process communication is maintained over the high speed network.

A variety of research projects are planned and underway in four major areas, theoretical foundations, algorithm implementation, support software, and run-time systems. The topics include: theory of computation, creation of scientific software, VLSI technology, computer architecture, compilers, databases, inductive inference and conceptual data analysis, and software systems research. The enhanced facility will serve as a catalyst for cooperative and productive research.

Cornell University; Robert L. Constable, Richard W. Conway, David J. Gries, and Alan J. Demers; *A Laboratory for Experiments on the Programming Process*; (MCS-8105763); $551,797; 12 mos.

This award will aid in the establishment of a major experimental facility to support research on the programming process at Cornell University. The investigators will consider a variety of topics including programming environments, the discipline of programming, and language design and implementation. While having distinct goals and clearly separate approaches the high degree of interaction among the researchers should provide results which strongly impact our understanding of programming.

The facility will include a variety of current and new computational resources interconnected by a local area network. While each researcher may access specialized resources for a particular project, all resources will be available to each user of the network. This environment can provide excellent com-

munication between research projects while matching the appropriate resource to an individual project. Cornell has been characterized as being engaged in highly individualized computer science research in an atmosphere of close rapport. This facility will enhance the research opportunities while maintaining this highly productive environment.

University of Washington; Jerre D. Noe, Hellmut Golde, Edward D. Lazowska and G. T. Almes; ***A Functionally Integrated Environment for Distributed Computation***; (MCS-8004111 A02); $1,145,000; 12 mos.

This award will aid in the establishment of a major experimental research facility at the University of Washington. The investigators will design and build a powerful new kind of computing environment to facilitate communication and cooperation among researchers in the Department of Computer Science. It will be based on a "building sized" highly-parallel computer consisting of a functionally integrated collection of physically distributed personal computers cooperating through a local network. The primary focus of the research will be the development and exploration of programming methodologies, adapted to a distributed concurrent environment, which give each user access to the power and diversity of the entire system.

University of Wisconsin-Madison; Lawrence H. Landweber, Robert P. Cook, David Dewitt, and Raphael Finkel; ***A Software-Partionable Multicomputer: A Testbed for Distributed Processing***; (MCS-8105904); $670,528; 12 mos.

This award will aid in the establishment of a major experimental facility to support research in databases, distributed processing, operating systems, multicomputer architecture, and numerical analysis. The investigators will implement and study a computer architecture that will exploit recent advances in computer and communication technology. The facility will include a multicomputer, a small number of high-performance personal computers, and a support center. The multicomputer will implement the target research environment. The personal computers will serve as prototypes for program development research projects. The support center computers will provide program preparation, simulation, file, and device services.

The multicomputer will be a research tool and a research object for a variety of projects. The implementation of the architecture and kernelized operating system will itself be a major effort. Once a prototype system is constructed it will allow the multicomputer to be logically partitioned for independent simultaneous use by different researchers. A large number of projects can then be supported to examine research issues in the respective areas.

## New Faculty Investigators in Experimental Research

University of Arizona; Timothy A. Budd; *Software Testing*; (MCS-8109547); $70,303; 12 mos.

This grant will establish a research program designed to consider all aspects of software testing and validation, from studies of the theory of testing, to the design and construction of actual testing tools. Initially a major part of this research will be to continue on-going studies concerning the mutation analysis software testing methodology, with particular emphasis on demonstrating the feasibility of using mutation analysis to test large production software components. A testing tool, written in RATFOR and designed to be portable to a large number of different machines, will be designed and constructed. A second part of this research will be to continue investigations in finding theoretical rationales for why and when methods that have been proposed will work, and to guide the search for new testing methods having theorietical justification.

University of Illinois-Urbana; Samuel N. Kamin; ***The Pragmatics of Final Data Type Specifications***; (MCS-8110087); $54,714; 12 mos.

A study of the pragmatics of a method of data type specification first presented by this investigator will be made. This method has the following important property, often said to characterize "abstractness" of a specification method: it is altogether free of "implementation bias." That is, it does not inherently favor any implementation over any other, the important point being that the programmer is freed to concentrate on real requirements. The development will be done in the stages.

1. A system for direct execution of specifications.
2. More ambitiously, a system for computer-assisted proofs of data type properties and of correctness of implementations.

In addition, the development of this system will provide practical experience in the use of the specification method in a large-scale programming project.

Purdue University; Dennis Gannon; *Algorithms and Architectures for Highly Parallel Solutions to Partial Differential Equations*; (MCS-8109512); $65,753; 12 mos.

This project will develop and experimentally validate new algorithms and architectures for highly parallel solutions to PDE computations. The machines under consideration will be very large arrays of processors classified according to the associated interconnection scheme. Three basic problems are to be explored. First, a class of algorithms suitable for general problems on irregular domains will be redesigned to run on large MIMD machines. By exploiting the low processor utilization of several new and existing methods, it should be possible to provide substantial improvements in overall convergence rates without degradation of performance. Second, for limited processor applications, architectures will be considered that are appropriate for algorithms employing self adaptive techniques such as locally refined grids. Third, through a system of simulation and experiment the problems of programming large MIMD arrays will be confronted.

Indiviudal Award; Deborah A. Joseph; *Computer Science Postdoctoral Fellowship*; (MCS-8114605); $48,000; 24 mos.

The research will involve the application of logic and model theory to complexity theory, and the fellowship instiution is Cornell University.

Columbia University; Yechiam Yemini; *Cooperative Distributed Computing in Computer Communication Networks*; (MCS-8110319); $96,202; 12 mos.

The objective of this research is to study various issues arising in the design and implementation of distributed cooperative network software, including algorithm design for networks, performance analysis of network algorithms, language and system constructs for network computations, semantics of network computing and software tools for a network environment.

An experimental study of algorithm design and implementation in computer networks will be made, by concentrating on the following three classes of algorithms, possessing both practical and scientific significance: real-time topology-based adaptive network algorithms, distributed position-location algorithms, and decentralized real-time resource sharing algorithms in networks. A network-testbed to be used for experimentation will be developed. A study of language and system constructs, and software environment needed to support the diffiicult task of developing network-based systems will be made.

## Computer Science Research Network (CSNET)

Rand Corporation; Anthony C. Hearn; *CSNET-Phonenet Operations and MMDF Development*; (MCS-8109321); $63,905; 12 mos.

This project is part of a cooperative effort among computer scientists to establish a computer-based communication network (CSNET) for computer science research groups in universities, industry, and government. A logical network spanning several existing computer networks including ARPANET, public packet networks, and Phonenet, a telephone-based relay system, will be established. Communication services to be provided initially include message services, file transfer, and and access to remote databases.

The Rand Corporation will help to establish, improve, and maintain the Phonenet component of the network. Phonenet will allow CSNET users to interface with an integrated communication environment which can have several transmission channels. Consequently, sending a message to a local user, to user on a machine attached through a local, national or international packet network, or one on a machine accessible only through a telephone call involves the same effort and procedures. The degree to which users are affected by changes underlying channels is minimized. It is also intended that the need for multi-hop relaying will be transparent to the user. Thus, Phonenet will provide a message and file transfer capability to a wide class of users. Rand effort will concentrate on Phonenet users who are physically located in the western half of the United States.

Objectives of CSNET are to help computer science research flourish through resource sharing and to stimulate new classes of research activities.

University of Delaware; David J. Farber; *CSNET-Phonenet Operations and MMDF Development*; (MCS-8109320); $247,530; 12 mos.

This project is part of a cooperative effort among computer scientists to establish a computer-based communication network (CSNET) for computer science research groups in universities, industry, and government. A logical network spanning several existing computer networks, including ARPANET, public packet networks, and Phonenet, a telephone-based relay system, will be established. Communication services to be provided initially include message services, file transfer, and access to remote databases.

Professor Farber will help to establish, improve, and maintain the Phonenet component of the network. Phonenet will allow CSNET users to interface with an integrated communication environment which can have several transmission channels. Consequently, sending a message to a local user, to a user on a machine attached through a local, national or international packet network, or to one on a machine accessible only through a telephone call involves the same effort and procedures. The degree to which users are affected by changes in underlying channels is minimized. It is also intended that the need for multi-hop relaying will be transparent to the user. Thus, Phonenet will provide a message and file transfer capability to a wide class of users. The University of Delaware effort will concentrate on Phonenet users who are physically located in the eastern half of the United States.

Objectives of CSNET are to help computer science research flourish through resource sharing and to stimulate new classes of research activities.

Purdue University; Douglas E. Comer and Peter J. Denning; *CSNET-Protocol Development*; (MCS-8109322); $78,615; 12 mos.

This project is part of a cooperative effort to establish a computer-based communication network (CSNET) among computer science research groups in universities, industry, and government. The investigators will build a logical network spanning several existing computer networks, including ARPANET, public packet networks, and Phonenet, a telephone-based relay system. Communication services to be provided initially include message services, file transfer, and access to remote databases. Costs for use of the net will depend on the service utilized. Access will be open to all computer science research groups.

Purdue University will be the principal site for CSNET protocol development. It will be the responsibility of Professors Comer and Denning to develop and integrate the standard CSNET operating system (VAX virtual UNIX) into the various sub-net components, including Phonenet (under development at the University of Delaware and Rand Corporation), ARPANET (through the TCP/IP software under development at Bolt, Beranek, and Newman, Inc.) and Telenet (through the network interface boards under development commercially). These subnet components will be built into a single package for distribution to CSNET users.

Objectives of the project are to help computer science research flourish through resource sharing and to stimulate new classes of research activities.

Department of Defense; Robert E. Kahn; *The CSNET Project*; (MCS-8116606); $458,944; 12 mos.

This activity is part of the Coordinated Experimental Research (CER) Program in computer science that includes a major effort to develop distributed operating systems at the University of Washington and to establish a computer-based communication network (CSNET) through projects at the University of Delaware, Purdue University, and the University of Wisconsin. Since access related activities of research and development are essential to the success of the CER Program, it is important for all of these universities to be connected directly to ARPANET. In particular, the purpose of the present action is to reimburse the Department of Defense for computer equipment and operating cost associated with the use of ARPANET during FY 1981 and FY 1982.

A by-product of providing ARPANET services to these universities will be to stimulate computer science research through shared resources.

University of Wisconsin-Madison; Lawrence H. Landweber and Marvin H. Solomon; *Technical support of CSNET & Service Host Functions in Support of CSNET*; (MCS-8109318); $733,219; 12 mos.

This project is part of a cooperative effort among computer scientists to establish a computer-based communication network for computer science research groups in universities, industry, and government. A logical network spanning several existing computer networks, including ARPANET, public packet networks, and Phonenet, a telephone-based relay system, will be established. Communication services to be provided initially include message services, file transfer, and access to remote databases. The University of Wisconsin-Madison will assist the entire project in several ways. First, it will establish three support groups: Technical Support Group, Organizational Support Group, and Policy Support

Group. Second, it will purchase or lease equipment as required by all components of the project. These support functions will be under the direction of Professor Lawrence H. Landweber.

In addition, Professor Marvin Solomon of Wisconsin-Madison will establish a "Service Host" running the UNIX operating system on a VAX computer. This host will be a time sharing facility for the CSNET user community and will provide several classes of service, including mail-only and virtual-terminal service.

Objectives of CSNET are to help computer science research flourish through resource sharing and to stimulate new classes of research activities.



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